Nepal Electricity Authority
Nepal

Nationwide Master Plan Study
on
Storage-type Hydroelectric Power Development in Nepal

Final Report
Appendix (2/2)

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Japan International Cooperation Agency

Electric Power Development Co., Ltd.

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Dudh Koshi Project (E-01)

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Introduction

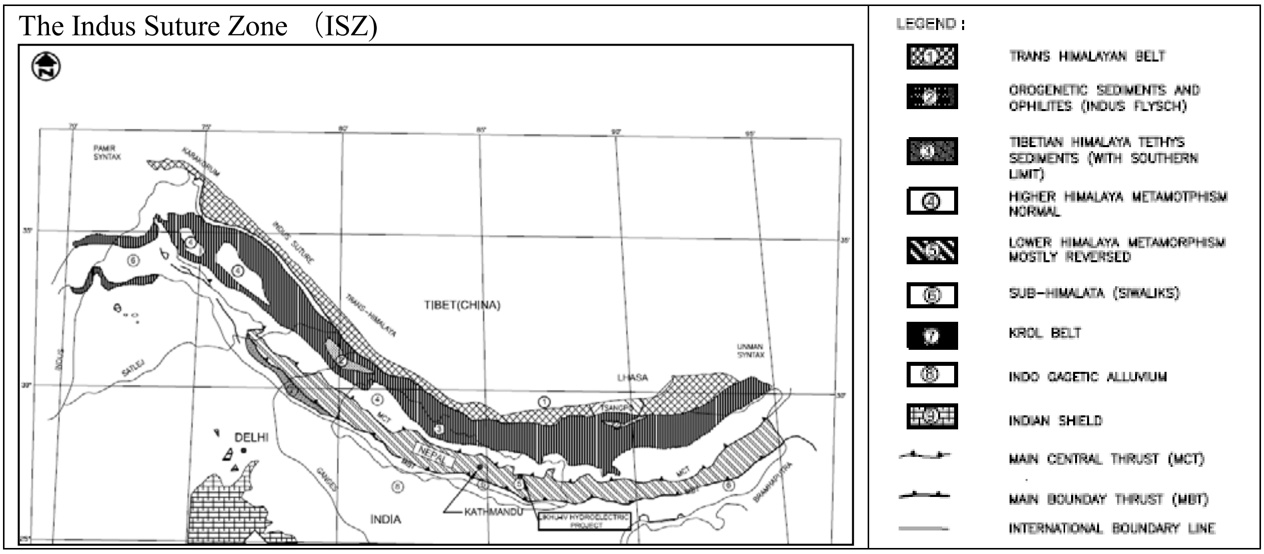
This Report deals with the Siesmic study of Nepal and summarized geology and engineering geology of Dudh Koshi project.

1 Seismic Study

1.1 Tectonic Setup of the Region

Tectonically Himalayas is divided into following five primary longitudinal tectonic areas （Figure 1.1） which from north to south are:

- The Terai and Indo-Gangetic Plain (IGP).
- The Sub-Himalayas (Siwalik Hills)
- The Lesser Himalayas
- The Higher/Tethyan Himalayas

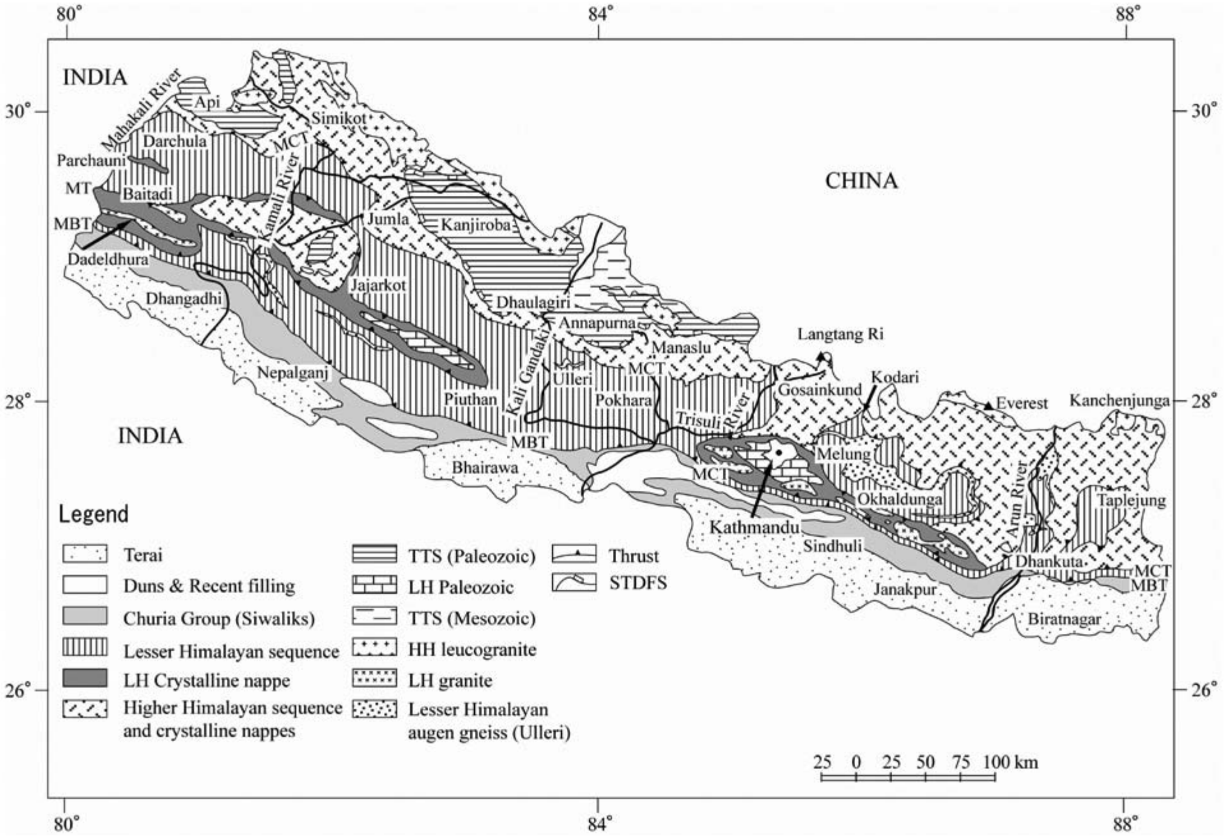


Source: Gansser, 1964

Figure 1.1: Tectonic Division of Himalaya

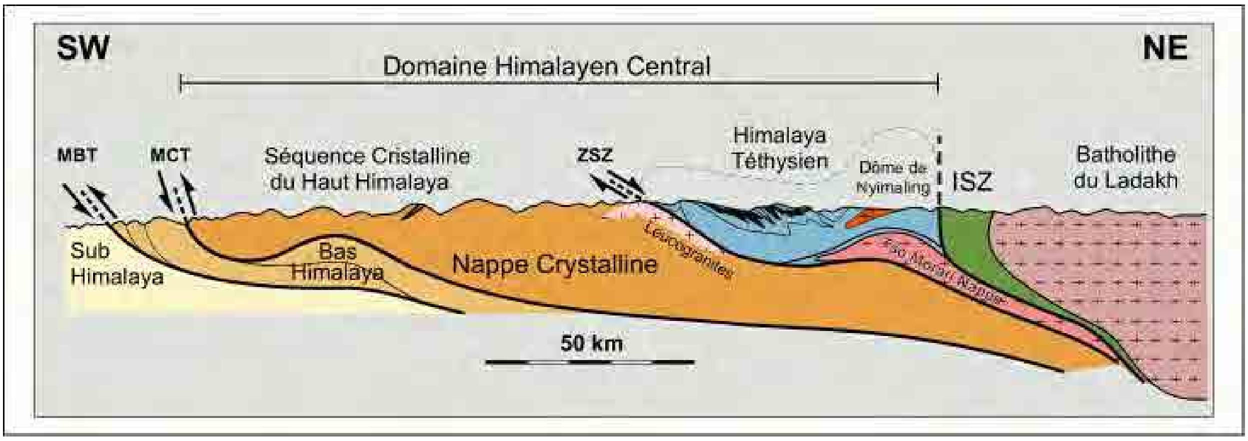
These tectonic areas are separated from each other by major, northeast-southwest trending tectonic structures (fault systems), that have continental proportions. Four of these tectonic areas are found within the territory of Nepal, while the Indus Suture Zone lies further lo the north in Tibet (Figure 1.2).

The Terai and the Indo-Gangetic Plain is separated from the Sub-Himalayas (Siwalik Hills) by the Himalayas Frontal Fault (HFF) System; the Sub-Himalayas are separated from the Lesser Himalayas by the Main Boundary thrust Fault (MBT); the Lesser Himalayas are separated from the Higher/Tethyan Himalayas by the Main Central Thrust Fault (MCT) and the Higher/Tethyan Himalayas are separated from the Tibetan Plateau by the Indus Suture Zone (Figure 1.3).



Note: LH, Lesser Himalaya; HH,Higher Himalaya; TTS, Tibetan-Tethys sequence; MBT, Main Boundary Thrust; MCT,Main Central Thrust; MFT,Main Frontal Thrust; STDS, South Tibetan Detachment System

Figure 1.2: Geological map of Nepal (modified after Upreti and Le Fort, 1999).



Source: Dezes 1999

Figure 1.3: Cross – Section Across Himalayas

The Physiography of these areas and the geology present in them are controlled to a large degree by the regional plate tectonic regime.

The vast Indo-Gangetic Plain tectonic area, which is represented by the Terai in the southern part of the Nepal, is bounded to the north by Himalayan Frontal Fault. It consists of alluvial deposits that have been derived from the Himalayas, and are estimated to be 4 to 6 km thick at the foot of the range (Sastri et al. 1971: Stoecklin. 1980). The sedimentary fill of the Indo Gangatic Plain is considered to be formed due to the uplift of the Himalayas and its subsequent erosion.

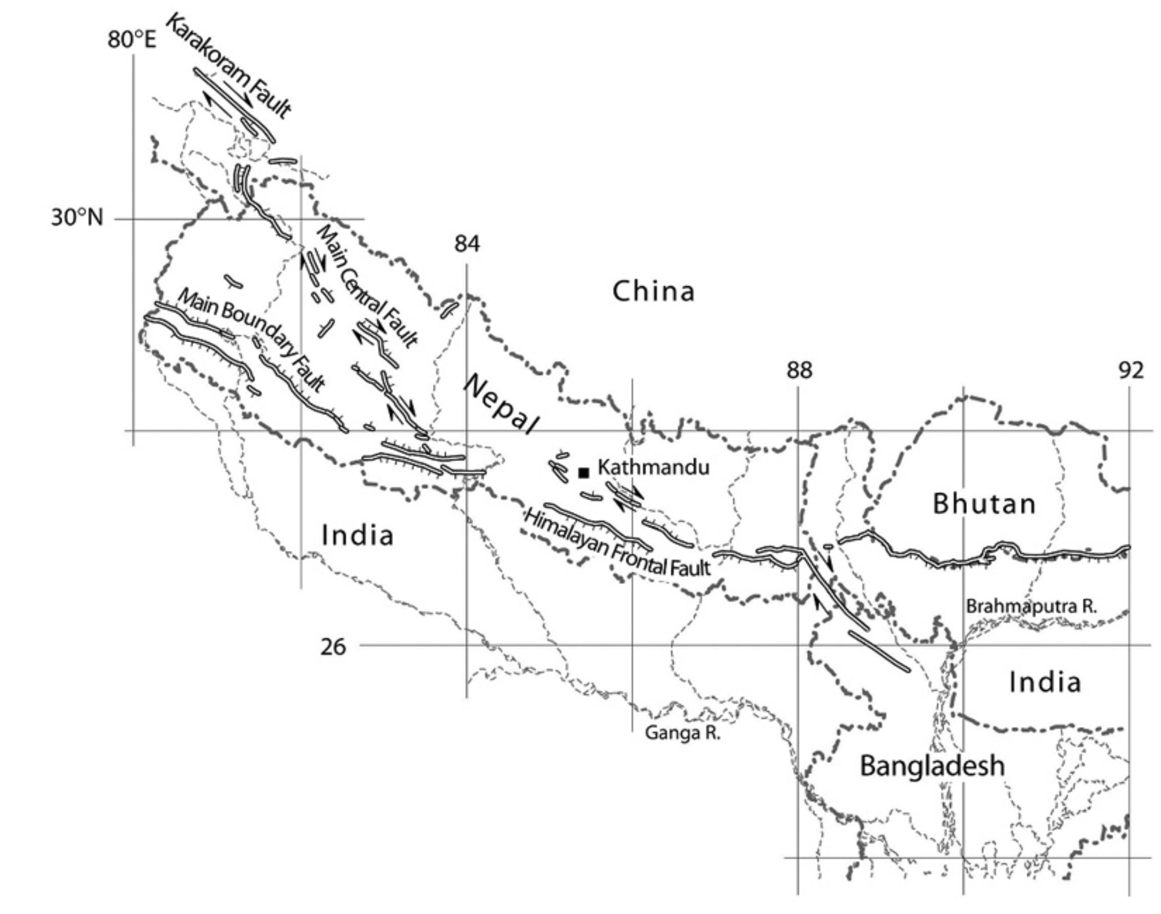
The Sub-Himalayas tectonic area, or Siwalik Hills located to the north of the Terai and is bounded to the north and south by the MBT and HFF respectively. The Siwalik Hills consist predominantly of the uniformly-dipping, openly-folded members of the Tertiary Siwalik formation, which is composed of a thick series of shales Sandstones and conglomerates of mid-Miocene to Pleistocene age (Fuchs, 1981; Himalayan Power consultants, 1988).

The Lesser Himalayas tectonic area is considered to be the area lying between the MBT and the northernmost trace of the MCT. The Lesser Himalayas consist primarily of thick sequence of low-grade meta-sedimentary rocks which includes phyllites, quartzites and carbonates, with minor amounts of granitic and metabasic rocks. These meta-sediments have been overridden by crystalline thrust sheets composed of schists, quartzites and high-grade gneisses (Windley, 1988). The overall geological structure is quite complex.

The Higher/Tethyan Himalayas tectonic area includes the Higher Himalayas and the Tethyan Himalayas. The Higher Himalayas is that region of the range where the mountains elevates to maximum and is bounded to the south by the MCT and to the north by a northward-dipping normal fault. The Higher Himalayas consist of a 3.5 to 10km thick section of high-grade metamorphic rocks (Windley, 1988) that has been thrust over the Lesser Himalayas to the south along the MCT (Pecher, 1978). This crystalline basement consists of schists, gneisses migmatites etc. and is succeeded upwards by Tethyan fossiliferous rocks of Paleozoic to Cretaceous age. The Tethyan Himalayas, located between the Higher Himalayas and the Indus Suture Zone (ISZ), consists of a nearly continuous sequence of conformable sediments ranging in age from the Paleozoic to early Tertiary (Molnar, 1984). The sediments are up to 6km thick (Windley, 1988) and consist of radiolarian shales, limestones, and flysch deposits.

The ISZ is located to the north of the Higher/Tethyan Himalayas. It represents the apparent line along which the Indian subcontinent and Eurasia collided (Molnar, 1984) about 40 to 55 million years ago (Windley. 1988). The ISZ consists of discontinuous relatively un-deformed ophiolite belt the presence of which suggests that a large majority of ocean floor lying between Eurasia and India has subducted (Molnar, 1984).

The Himalaya is one of the most active mountain belts in the world. The active faults, in and around this belt are direct indicators of recent crustal movement due to the collision between the Indian and Eurasian plates. Active faults, in the Nepal Himalaya, (Figure 1. 4), are distributed mainly along the major tectonic elements as well as older geological faults and are classified into four groups (Nakata, 1982); the Main Central Active Fault system, the active fault in Lower Himalayas, the Main Boundary Active Fault system and active faults along the Himalayan Front Fault (equivalent to MFT). Among these, active faults along the MBT and MFT are most active and have potential to produce large earthquakes in the future (Lave and Avouac, 2000; Chamlagain et al., 2000).



Source: Deepak Chamlagain, 2009

Figure 1.4: Active faults in and around Nepal Himalaya

1.2 Geotectonic Location of the Screened Hydroelectric Reservoir Projects

The Geotectonic location of the screened hydroelectric project is presented in Table 1.1.

Table 1.1: Location of the Screened Project for Master Plan Study

S.N.	Project Name	Geographic Location	Geo-tectonic Location
1	**C-08 Andhi Khola**	Western Nepal	Lesser Himalaya – slates and carbonates
2	**W-02 Chera-1**	Mid-Western Nepal	Lesser Himalaya – phyllites, quartzites and carbonates
3	**E-01 Dudh Koshi**	Eastern Nepal	Lesser Himalaya – Phyllites, quartzites and carbonates and gneisses and schists (parts of Lesser Himalayan Crystallines – Klippe components)
4	**C-02 Lower Badigad**	Western Nepal	Lesser Himalaya – slates and carbonates
5	**W-05 Lower Jhimruk**	Mid-Western Nepal	Lesser Himalaya – slates, quatzites and carbonates
6	**W-06 Madi**	Mid-Western Nepal	Lesser Himalaya – slates, quatzites and carbonates
7	**W-23 Nalsyau Gad**	Mid-Western Nepal	Lesser Himalaya - Slates and carbonates
8	**W-25 Naumure (W.Rapti)**	Mid-Western Nepal	Sub-Himalaya and Lesser Himalaya – Sandstones, shales in sub-Himalaya and slates, quartzites and carbonatres
9	**E-17 Sun Koshi No.3**	Central Nepal	Lesser Himalaya – slates, carbonates and phyllites and quartzites
10	**E-06 Kokhajor-1**	Central Nepal	Sub-Himalaya - Sandstones and shale

Except for the Naumure and the Kokajhor rest of the screened project are located in the Lesser Himalayan area while former are located in the Sub-Himalayan Zone. The Naumure, dam and powerhouse is located in the Sub-Himalaya while the larger portion of the reservoir is located in the Lesser Himalayan meta-sediments with the MBT passing across the reservoir area.

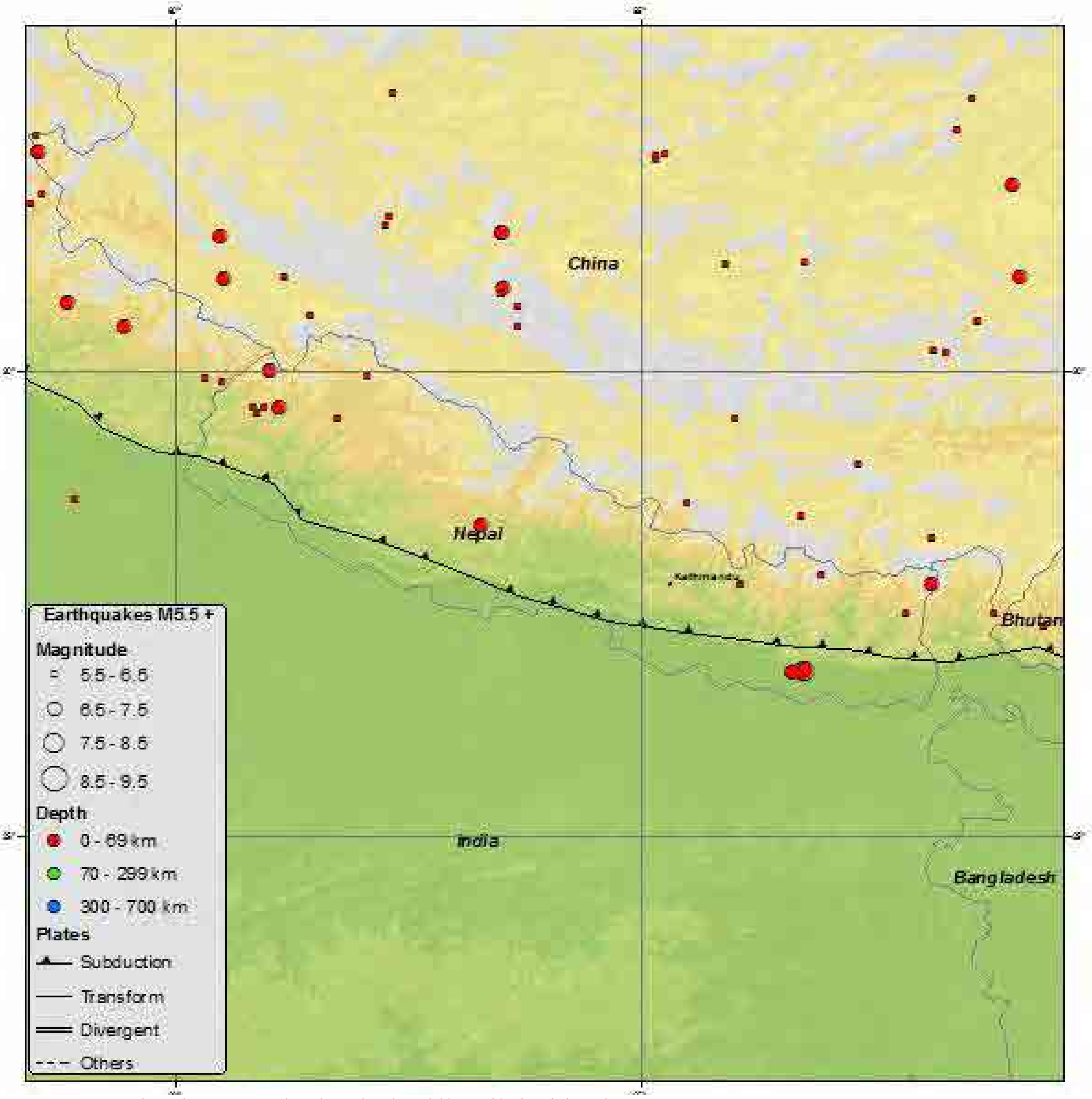
The Sub-Himalayan rocks comprise of the thick alternating beds of sandstones and slates which shows coarsening upward trends. The rock sequences repeats in the north south profile due to the large scale open folding as well as due to regional longitudinal thrust faults. One of such thrust fault passes upstream of the dam location in the Naumure site bringing Lower Siwalik fine sandstones and shale over the Middle Siwalik Sandstones.

The project locations in the Lesser Himalaya are mostly confined within the meta-sedimentary sequences except the Dudh Koshi site where a part of the headrace tunnel and powerhouse site is located within the Lesser Himalayan crystalline along the structural depression supporting the crystalline rocks of Higher Himalaya as Klippe.

The thick succession of the Lesser Himalayan meta-sediments comprising of slates, carbonates, quartzites and phyllites is considered relatively atochthonous. However, the rock sequences are repeated across the transverse profiles mostly due to thrust faults. Such thrust faults repeating the sequences are observed in the Lower Jhimruk, Madi, Naumure and Sun Koshi sites. At the Barigad site, an active fault (Barigad Fault, refer figure 4) traverses parallel to the Barigad river for a considerable distance along the reservoir. Similarly the Fault separating the slates from Phyllite also align parallel to the active falult shown east of Kathmandu valley at Sun Koshi site (refer figure 4)

1.3 Historical Earthquakes

Figure 1. 5 presents the seismic map of Nepal since 1950 to present. Nepal has experienced numerous large earthquakes over the past several centuries that have resulted in property damage and loss, injury and death. The earliest recorded earthquake was in 1255, and apparently occurred near Kathmandu. It had maximum epicentral Modified Mercalli Intensity (MMI) of X which suggests that its magnitude could have been approximately M 7.7. An earthquake with the same approximate magnitude occurred at the same location in 1408, while in 1681, an approximate magnitude M 7.0 also occurred there. At least four approximate magnitude M 7.0 earthquakes are thought to have occurred near Kathmandu and to the northwest in 1833 and in 1869. Given the large uncertainties in the location of the early earthquakes in Nepal, these epicentral locations must be considered as being very approximate.



Source: earthquake.usgs.gov/earthquakes/world/nepal/seismicity.php

Figure 1.5: Seismicity Map - 1900 to Present

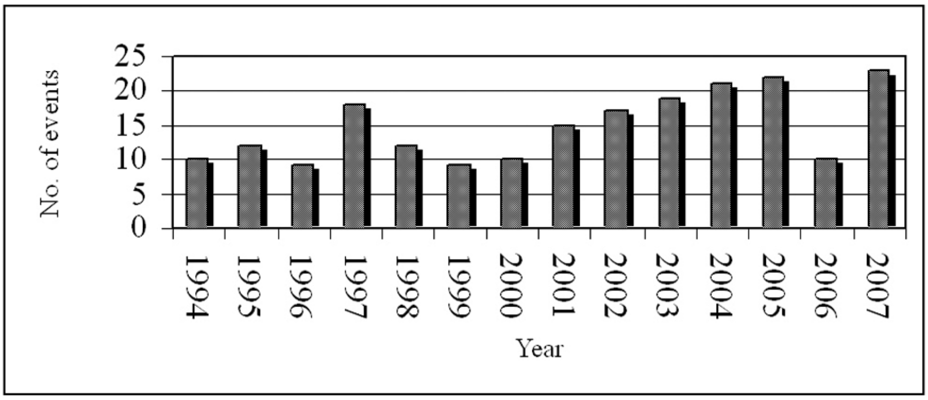
Eastern Nepal was the location of the great 1934 Bihar-Nepal earthquake. It had an estimated Magnitude of about M 8.4., and its epicentre was located north of Chainpur in Eastern Nepal. This earthquake destroyed more than 80,000 homes and damaged another 104,000. The majority of this destruction and damage reportedly occurred in the Kathmandu Valley and in the plains of the eastern Terai. The 1988 magnitude M 6.6 Udayapur District and resulted in more than 700 deaths and the destruction of damage to more than 65,000 private and government residences and buildings. This damage was concentrated in the plains of the eastern Terai in a pattern similar to the 1934 earthquake.

These moderate to great-magnitude (approximate magnitude of M 5.5-8.0+) historic earthquakes and in particular the 1988 Udayapur earthquake have shown how vulnerable different structures in Nepal are to earthquake loading.

Western Nepal, has also been subjected to numerous moderate and large earthquake in the past. A magnitude M 7.7 earthquake occurred in the Bajhang District in 1916. While a magnitude M 6.5 earthquake occurred in the same district in 1980 resulting in 46 deaths and the destruction or damage to more than 25,000 homes. The Almora area of India just west of the Nepal border was the location of a magnitude M 7.3 earthquake in 1913 and a magnitude M 6.1 event in 1991. The 1991 earthquake resulted in more than 500 deaths and the destruction and damage of homes, bridges and telecommunication facilities.

1.4 Earthquake Catalogue

Seismological Centre (NSC) under the Department of Mines and Geology has been continuously monitoring the earthquake events since 1978. NSC documentation shows that between 1994 and 1999, the average frequency of earthquakes having magnitude between two and less than 5 was approximately 10 per day, magnitude 6 and less than 7 was 1 in per 6 years. Similarly, total number of earthquakes of magnitude 2 to less than 7 between 1994 and 1999 were approximately 700, 900, 1500, 1700, 2200, and 1600 respectively (Upreti, 2001). Although the general trend shows that number of earthquakes is increasing in Nepal Himalaya (Figure 1.6)



Source: Deepak Chamlagain, 2009

Figure 1.6: Number of Earthquakes (Ml >4) occurring in Nepal between 1994 and 2007.

1.5 Micro-seismicity

The territory of Nepal is characterized by a very intense microseismic activity. All events with magnitude above 2.0 are computed for the period May 1994 and January 1998 by Pandey et al (1999) and presented in Figure 1.7.

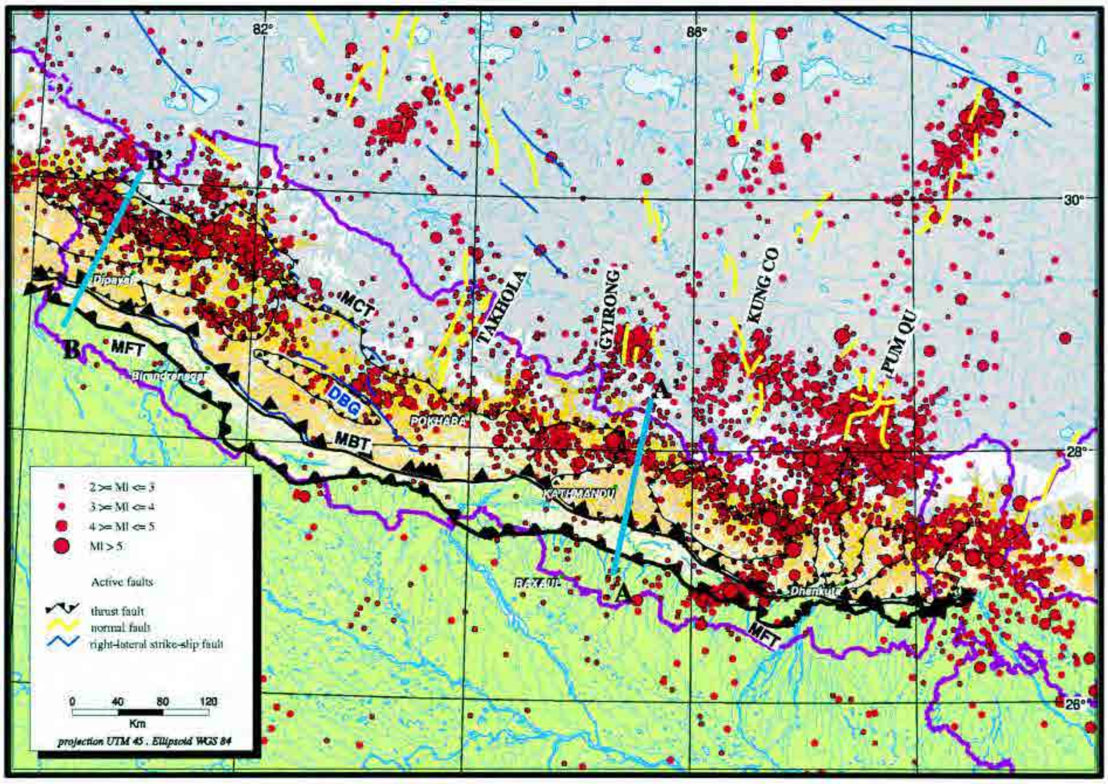


Fig. 1.7: Microseismicity map of Nepal monitored between May 1994 and January 1998.

Microseismic activity is particularly intense in Eastern and Far-Western Nepal. The major feature of microseismicity in Nepal is the narrow belt of seismicity that follows approximately the topographic front of the Higher Himalaya. This seismic belt extends throughout Nepal from west to east.

1.6 Seismic Evaluation of the Screened Projects

Despite the urgent need of hazard assessment of the country, Nepal has not taken enough initiatives to understand the level of seismic hazard. In order to determine seismic coefficient, a seismic design code for Nepal prepared by Bajrachrya (1994), divided the whole country into five seismic risk zones (Figure 1.8).

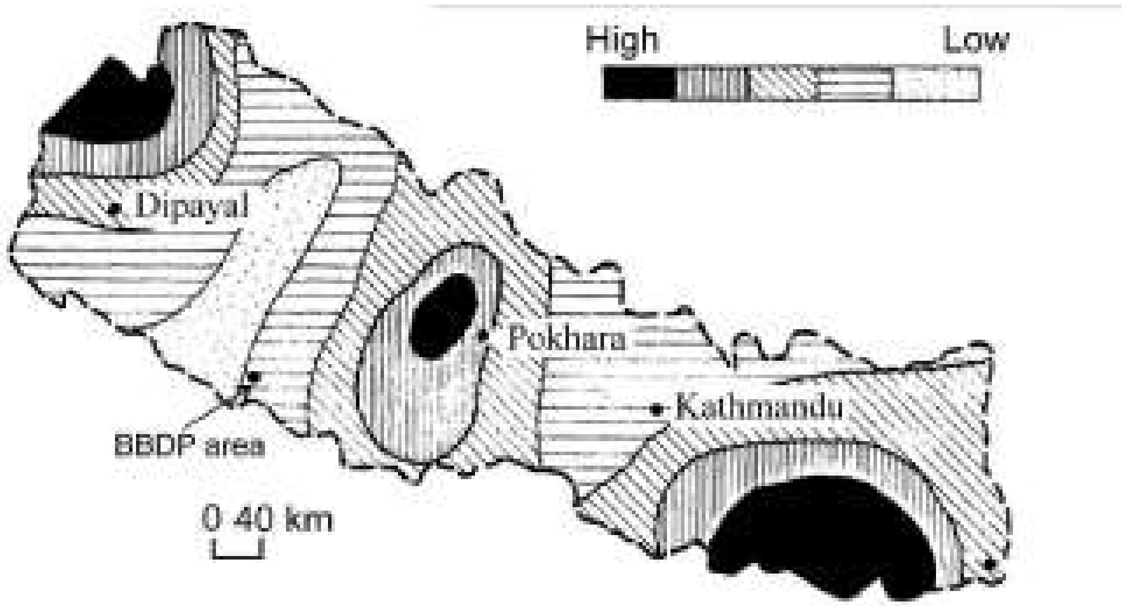


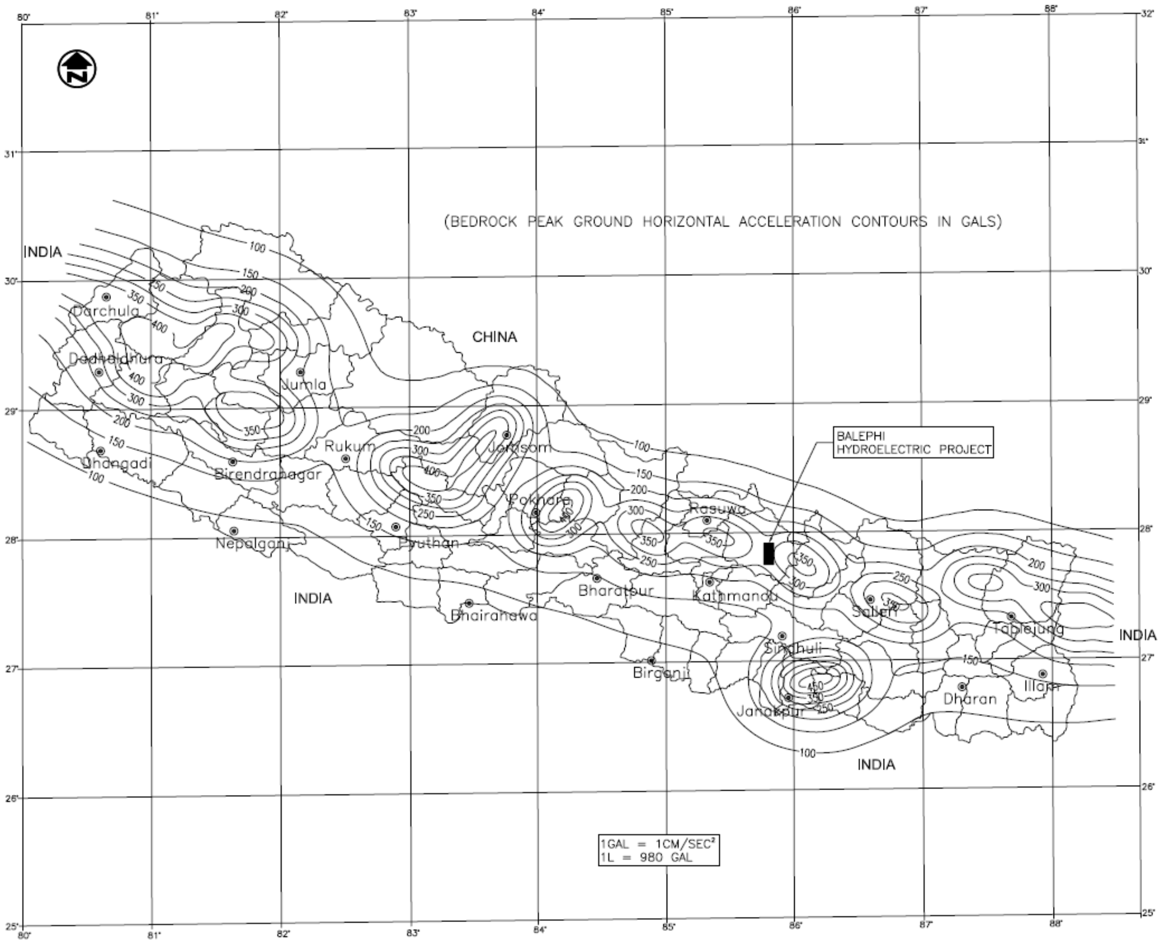
Figure 1.8: Seismic risk map of Nepal (after Bajracharya, 1994)

As per this coding the screened projects fall in different seismic risk zones (Table 1.2).

Table 1.2: Estimated Seismic Risk Zone as per the Seismic Risk Map of Bajracharya, 1994

S.N.	Project Name	Geographic Location	Seismic Risk Zone
1	**C-08 Andhi Khola**	Western Nepal	Moderately High
2	**W-02 Chera-1**	Mid-Western Nepal	Low
3	**E-01 Dudh Koshi**	Eastern Nepal	Moderate
4	**C-02 Lower Badigad**	Western Nepal	Moderately High
5	**W-05 Lower Jhimruk**	Mid-Western Nepal	Moderate
6	**W-06 Madi**	Mid-Western Nepal	Moderately Low
7	**W-23 Nalsyau Gad**	Mid-Western Nepal	Low
8	**W-25 Naumure (W.Rapti)**	Mid-Western Nepal	Moderate
9	**E-17 Sun Koshi No.3**	Central Nepal	Moderate
10	**E-06 Kokhajor-1**	Central Nepal	Moderately High

Later Pandey et al. (2002) has prepared a seismic hazard map for territory of Nepal (figure 9. In this map, the districts prone to the various intensities of hazards are clearly shown. As per this hazard map the screened projects fall under the following hazard zones (Table 1.3).



Note: Bedrock peak ground horizontal acceleration is calculated for five hundred years return period. Contour interval is 50 gals.

Figure 1.9: Seismic Hazard Map of Nepal, Pandey et al. (2002)

Table 1.3: Estimated Seismic Hazard as per the Seismic Hazard Map of Pandey et.al, 2002

S.N.	Project Name	Geographic Location	Seismic Hazard (mgal) including reservoir area
1	**C-08 Andhi Khola**	Western Nepal	150 – 200
2	**W-02 Chera-1**	Mid-Western Nepal	300-350
3	**E-01 Dudh Koshi**	Eastern Nepal	150-200
4	**C-02 Lower Badigad**	Western Nepal	150 -250
5	**W-05 Lower Jhimruk**	Mid-Western Nepal	100-150
6	**W-06 Madi**	Mid-Western Nepal	150-200
7	**W-23 Nalsyau Gad**	Mid-Western Nepal	250 -300
8	**W-25 Naumure (W.Rapti)**	Mid-Western Nepal	100-150
9	**E-17 Sun Koshi No.3**	Central Nepal	150-200
10	**E-06 Kokhajor-1**	Central Nepal	150-200

2 Dudh Koshi Project

This Chapter deals with the engineering geological investigations in the Dudh Koshi hydroelectric dam projects. FS report (1998) was reviewed. Geology and engineering geology of this project are summarized below.

2.1 Regional Geology

In the regional geological framework of the Nepal Himalaya, the Dudh Koshi Project site is located in the Lesser Himalaya bounded on the north by Main Central Thrust (MCT) and south by Main Boundary Thrust (MBT). In the limits of these two regional thrust structure separating Lesser Himalaya with Higher Himalaya and Lesser Himalaya with Sub-Himalaya, the rock sequences of Lesser Himalayan meta-sediments (Midland Group, DMG 2011) and Lesser Himalayan Crystallines (Kathmandu Group, DMG, 2011) have been represented in the Dudh Koshi Project sites (Figure 2.1).

The Lesser Himalayan meta-sediments is comprised of greenish grey to grey phyllites, psamitic phyllites, and quatzites, with dominance of psamitic phyllites. The dam site and the reservoir area of the project is underalain by this rock sequence. The headrace tunnel cut across the greey to greenish grey phyllites and quartzite sequence immediately south of the intake, which then pass through the augenh gneiss and the coarse textured, garnetiferous muscovite –biotite schists with interlayers of calc silicates and chloritic scists. Further south dominant crystalline limestone, and dolomite with pyllitic schist intercalation passes to coarse garnetifiersous muscovite –biotite schists, psametic schist in the lower section of headrace tunnel and the powerhouse area. These metamorphosed rock sequence of the headrace tunnel and powerhouse site constitute the Lesser Himalayan crystallines preserved along the tectonic depression in the region in the form of klippe.

2.2 Site Geology

The Dudh Koshi project area belongs to Okhaldhunga district and Khotang district, east in Nepal. The dam site is located on Dudh Koshi river. The powerhouse site is located on the left bank of the Sunkoshi river.

The project area lies in the Lesser Himalayan Zone, and is underlain by phyllite, quartzite, limestone, schist and gneiss (Figure 2.2).

Reservoir and its surrounding area are underlain by phyllite and subordinate quartzite. Thotane fault crosses the reservoir near the dam site. Reservoir area is watertight because of the lack of permeable rocks such as limestone. No major instability is observed in the reservoir area.

In dam site, quartzite is distributed on the left bank, and phyllite on the right bank. Bedding planes incline 10 to 30 degrees toward west or northwest, i.e. toward downstream or right bank. Rocks are permeable as indicated by many test sections of more than 10 Lu. Quartzite is more permeable than phyllite. The groundwater level of the left bank is slightly higher than river level. But, it is expected that permeability of bed rock decrease as the depth increase. The depth of river deposits was confirmed to be 19.2m by a boring.

Headrace tunnel route passes the mountains between Dudh Koshi river and Sunkoshi river. The length of the tunnel is about 14km. The route passes, from intake to surge tank, the section composed of phyllite and quartzite, the section of phyllite and limestone, and the section of schist and gneiss (Fugure 2.3). This tunnel route encounters 3 major faults. Strike of bedding plane or foliation is NE-SW and at an angle of about 60 degrees to the tunnel direction. They incline toward intake in about 3km long section from intake to Dudh Koshi Fault, and toward surge tank in the remaining section. Overburden of this tunnel is up to1250m.

Powerhouse is underground type and its site is located on the left bank of Baiku Khola river, a tributary on the left bank of Subkoshi river. This site is composed of schistose gneiss, which is strong. RQD of this rock is 72%. Foliation of the gneiss inclines at angles of 20 to 50 degrees toward northwest.

For concrete aggregate, river sand and gravel distributed in the vicinity of the dam site are not suitable in terms of soundness, but quartzite distributed in the vicinity of the dam site is available. This quartzite is also available for rock materials. It has been confirmed that enough volume of soil materials are distributed in the vicinity of the dam site.

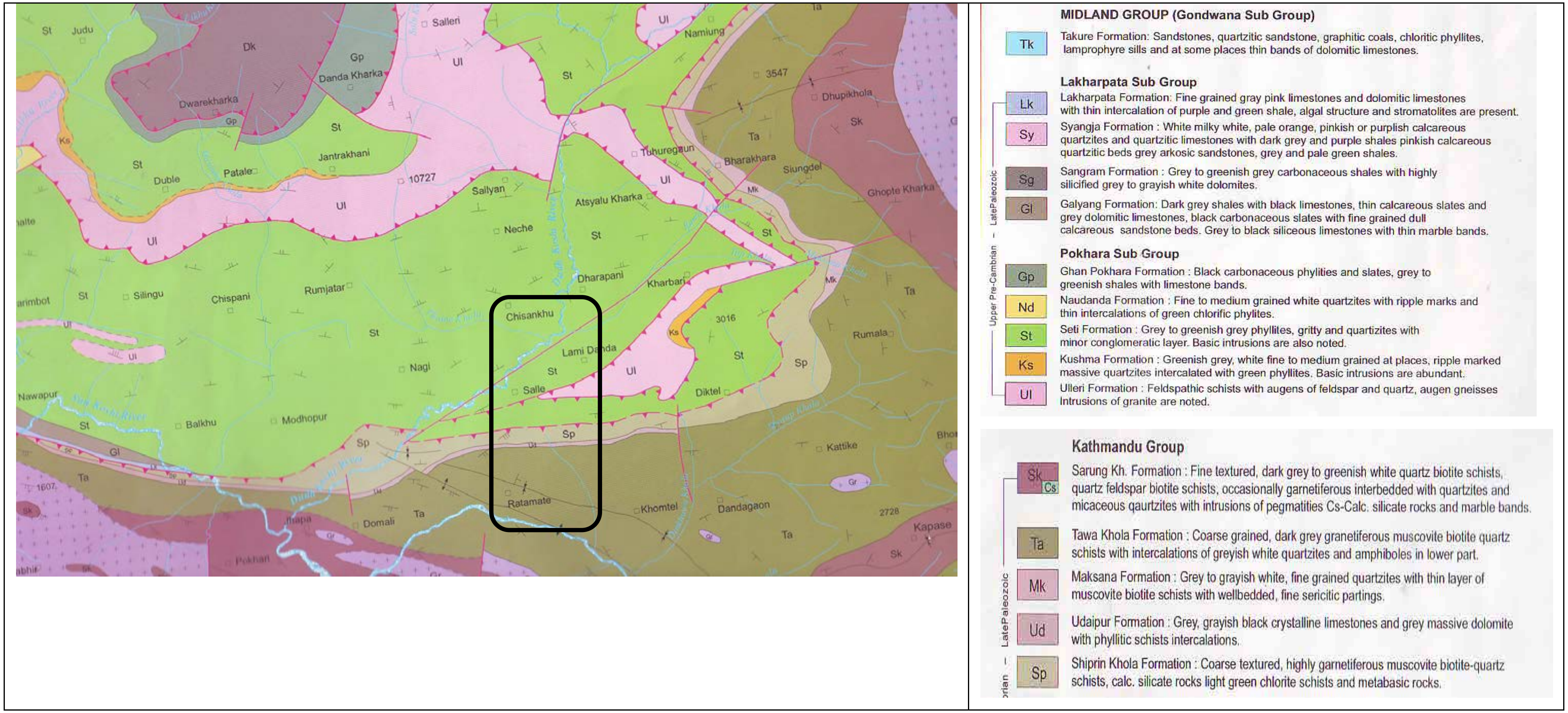


Figure 2.1: Regional Geological Map (DMG, 2011)

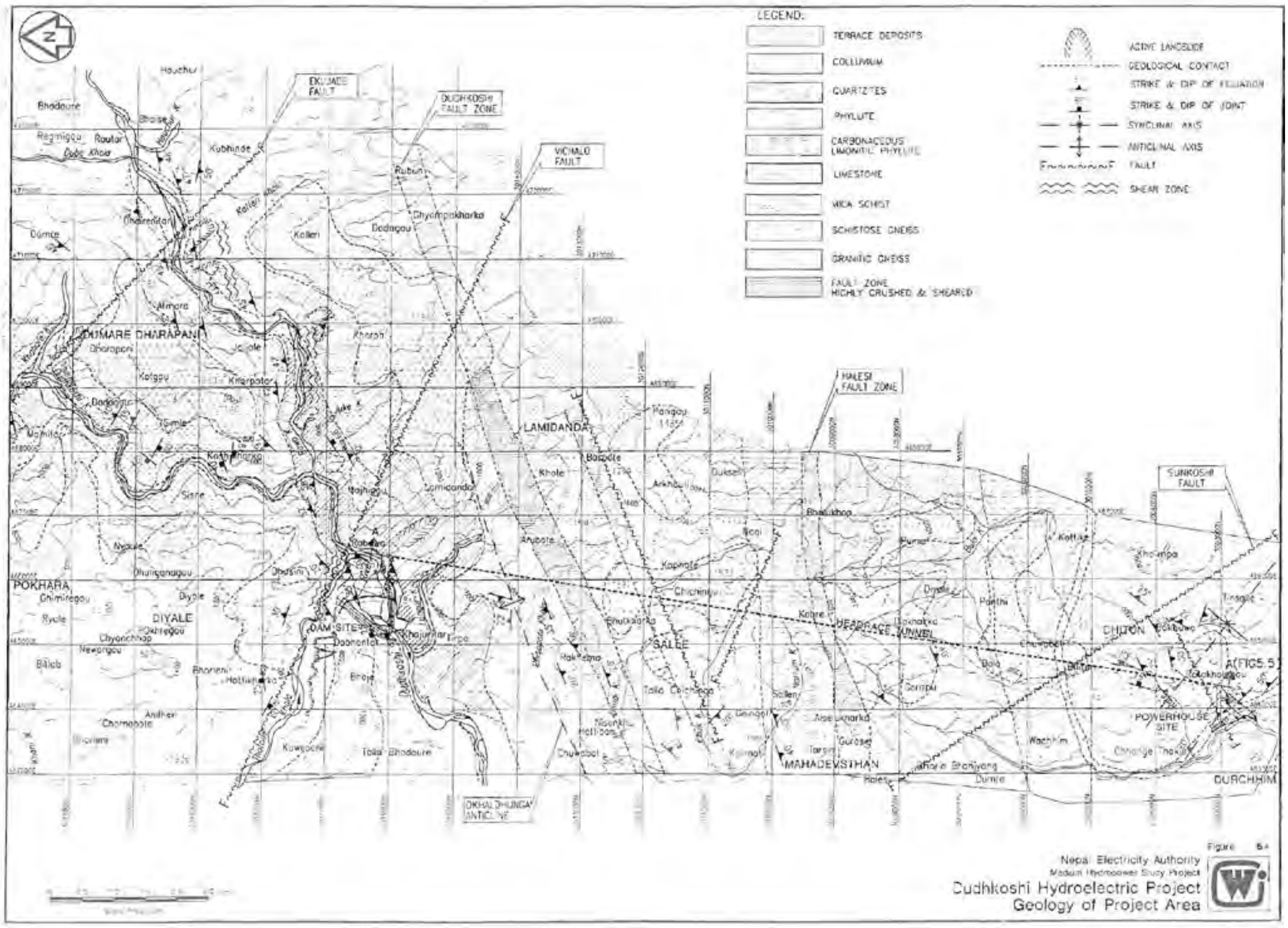


Figure 2.2: Geological map of the project area

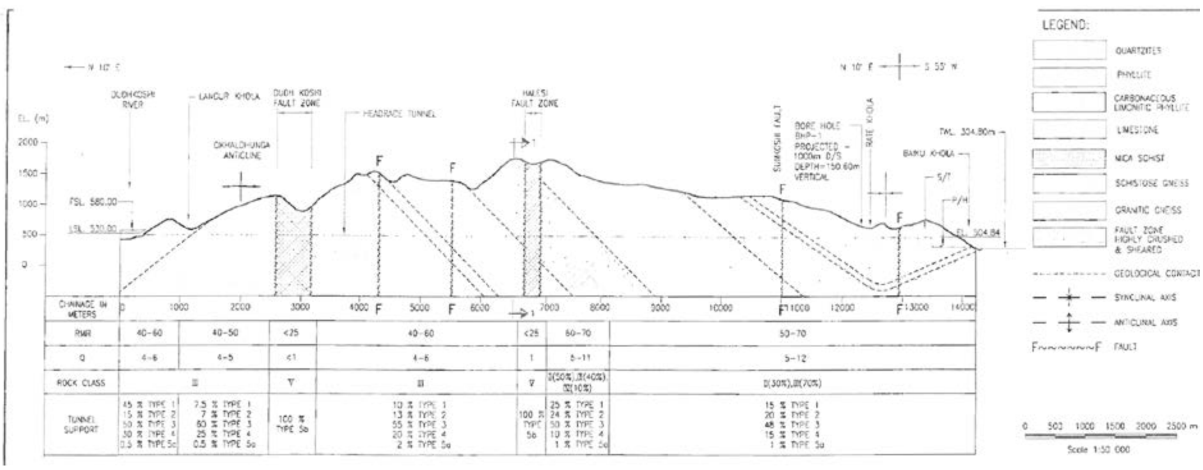


Figure 2.3: Geological profile along headrace tunnel

Table 2.1: Geological Study Team Members and Itinerary of the Field Visits

S.N.	Name of Project	District	Date of field visit	Name of the Geologlist	Investigation method
1	Sunkoshi	Kavrepalanchowk and Sindhuli	8th July – 14th July, 2012	Dr. Kamala K. Acharya Mr. Baburam Gyewali Mr. Laxman Subedi	Geological reconnaissance survey
2	Andhi khola	Syanja	9th July - 15th July, 2012	Dr. Subesh Ghimire Mr. Asim Rijal Mr. Yogendra Mohan Shrestha	Geological reconnaissance survey
3	Chheda khola	Jajarkot	8th July – 19th July, 2012	Dr. Megh Raj Dital Mr. Narayan Adhikari Mr. Santosh Adhikari	Geological reconnaissance survey
4	Lower badigad	Gulmi	9th July - 15th July, 2012	Dr. Sunil K. Dwivedi Mr. Lalit Rai Mr. Gautam Khanal	Geological reconnaissance survey
5	Lower Jhimruk	Pyuthan and argakhanchi	10h June - 16th June, 2012	Dr. Subesh Ghimire Mr. Pratap Bohora Mr. Ajit Sapkota	Geological reconnaissance survey
6	Madi	Rolpa	10th June – 16th June, 2012	Dr. Kamala K. Acharya Mr. Nirmal Kaphle Mr. Laxman Subedi	Geological reconnaissance survey
7	Naumure	Argakhanchi and Pyuthan	10th June - 16th June, 2012	Dr. Sunil K. Dwivedi Mr. Lalit Rai Mr. Saunak Bhandari	Geological reconnaissance survey
8	Kokhajor	Kavrepalanchowk	29h September - 8th October, 2012	Dr. Megh Raj Dital Mr. Narayan Adhikari Mr. Santosh Adhikari	Geological reconnaissance survey

Annex 2: Geological Survey Report

Kokhajor 1 (E-06)

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Introduction

This Report deals with the engineering geological investigations in the Kokhajor 1 hydroelectric dam projects. This project area was surveyed by Professor Dr Megh Raj Dhital, Mr Narayan Adhikari, and Mr Santosh Adhikari between 29 September and 8 October 2012.Geology and engineering geology of this project are summarized below.

1. Kokhajor 1 Project

1.1 Geology of project area

The geological map (Figure 1.1) by Stöcklin and Bhattarai (1977) shows the Lesser and Higher Himalayan rocks represented by the Nawakot Complex and Kathmandu Complex, respectively. The Lesser Himalayan rocks form a very narrow zone just north of the MBT and they are immediately thrust over by the rocks of the Kathmandu Complex along the MCT.

Most of the Project area belongs to the Lower, Middle, and Upper Siwaliks (Figure 1.2). The Pre-Siwalik outliers shown on some published geological maps were not encountered in the field while passing through the headrace tunnel and penstock alignment, where mainly the Middle and Lower Siwaliks crop out.

The rocks composing the project area are represented primarily of the Siwaliks with a minor proportion of the Lesser Himalayan and Higher Himalaya rocks.

Lithology: The Neogene Siwalik Group of rocks are the product of the disintegration of the Higher Himalayan and Lesser Himalayan rocks by various rivers. These molasses are soft and relatively less indurated than other Himalayan rocks. They are frequently classified into the Lower, and Middle, and Upper divisions. The Lower Siwaliks crop out in the vicinity of the powerhouse area and they are thrust over the Upper Siwaliks along the Marin Khola Thrust in the Marin Khola area (Figure 1.2). They consist of relatively soft, medium- to fine-grained sandstones and mudstones. The sandstone and mudstone alternation ranges in thickness from a few metres to tens of metres. Generally the transition from sandstone to mudstone is imperceptible whereas the contact between the underlying mudstone and overlying sandstone is sharp and frequently wavy to irregular.

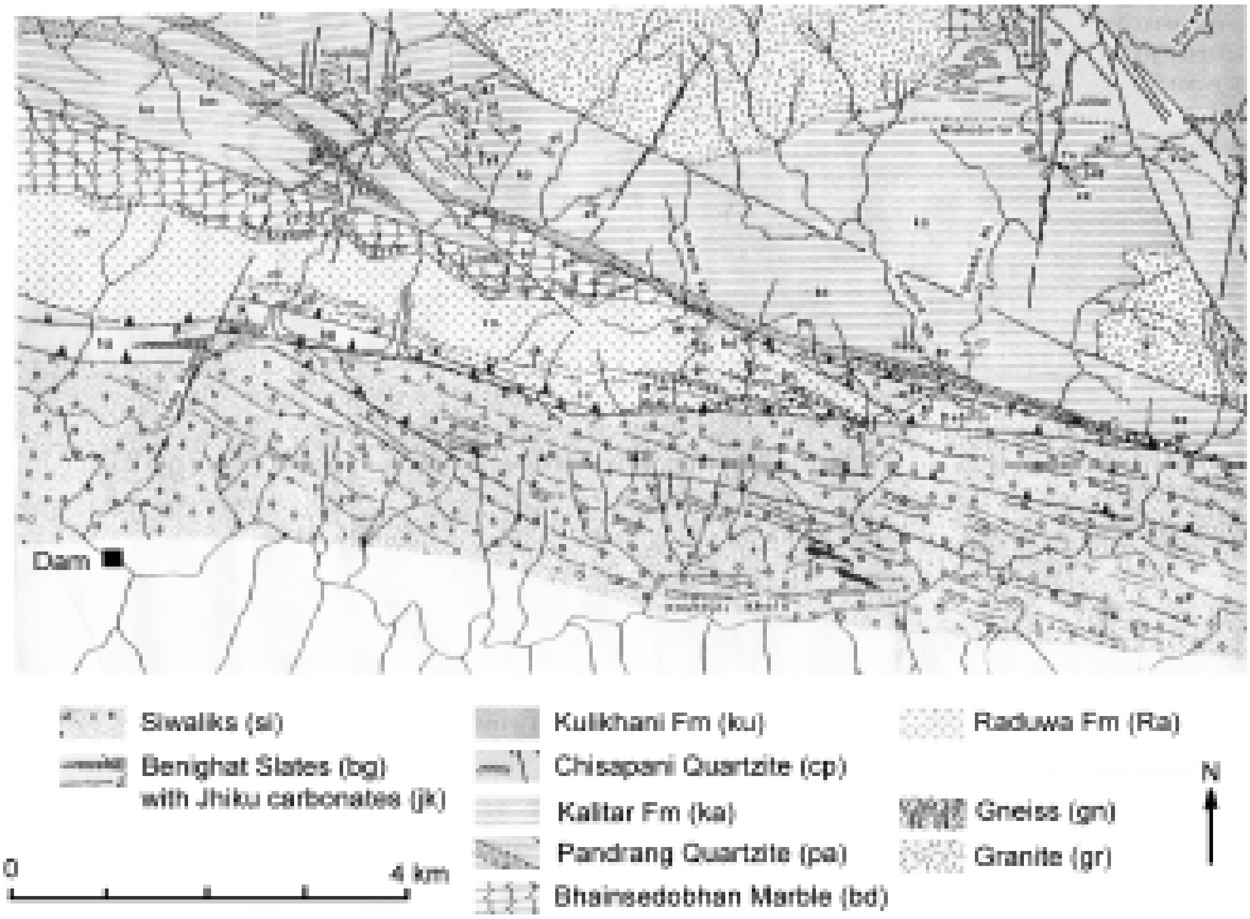

Figure 1.1: Regional geological map of the Kokhajor Hydroelectric Project area (Stocklin and Bhattarai 1977)

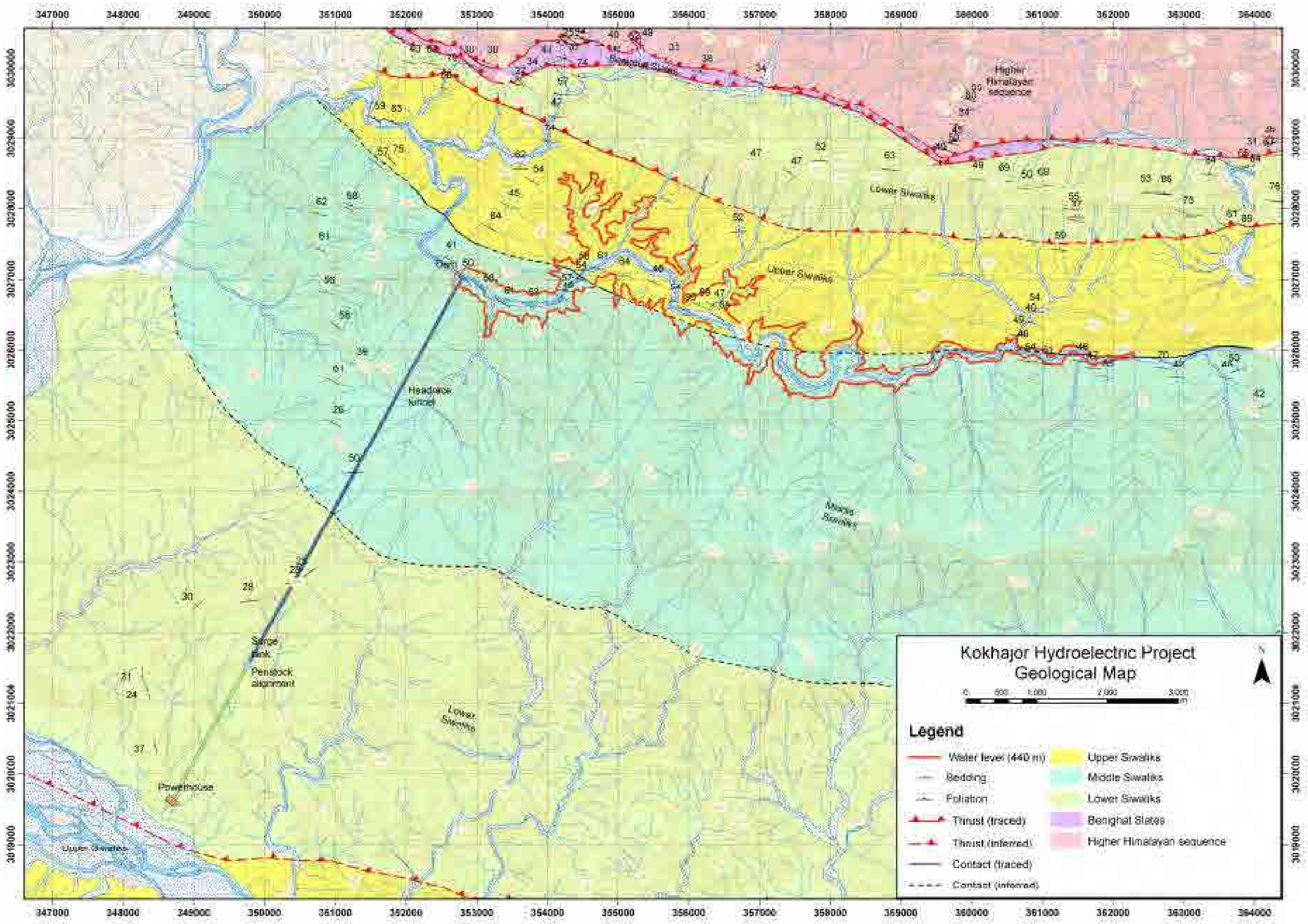

Figure 1.2: Geological map of the Kokhajor Hydroelectric project area showing various rock types and main structures

The fluvial cycles of the Lower Siwaliks are followed stratigraphically upwards by the grey "pepper-and-salt" sandstones consisting of detrital muscovite, biotite, feldspar, and quartz. The Middle Siwalik sandstones are generally coarse- to very coarse-grained, moderately indurated, and relatively strong. The extremely thick (more than 25 m) Middle Siwalik sandstones are cross-laminated, frequently pebbly, and sometimes calcareous.

The Upper Siwaliks in the project are comprise mainly soft but sometimes well cemented and hard (near the dam site) pebble-, cobble- to boulder-conglomerates interbedded mainly with pebbly sandstones. There are also subordinate mudstone beds in the Upper Siwaliks. But conglomerates and sandstones predominate over the mudstones. The Upper Siwaliks are grey, light yellow to brown in colour and an individual conglomerate, sandstone, or mudstone bed ranges in thickness from 5 m to 25 m and more.

The overall bedding and foliation of rocks is oriented due NE and their dip is moderately steep (i.e., 51 degrees). The stereographic projection of bedding and foliation is presented in Figure 1.3 where a strong concentration of of S-planes is observed.

Quaternary deposits: Quaternary deposits are widespread in the study area (Figure 1.6). They are classified under colluvial, residual, and alluvial deposits. Most of the alluvial deposits are concentrated along the main river courses, where they range in thickness from 10 m to 30 m and more. The colluvial deposits are distributed along concave slopes and valley flanks. They are from a few metres to tens of metres thick. But generally their thickness does not exceed 10 to 15 m. Most of colluvial soil was derived from sliding and disintegration of rock by waters. The residual soils are not well developed and present on hilltops and ridges where their thickness is less than 10 m.

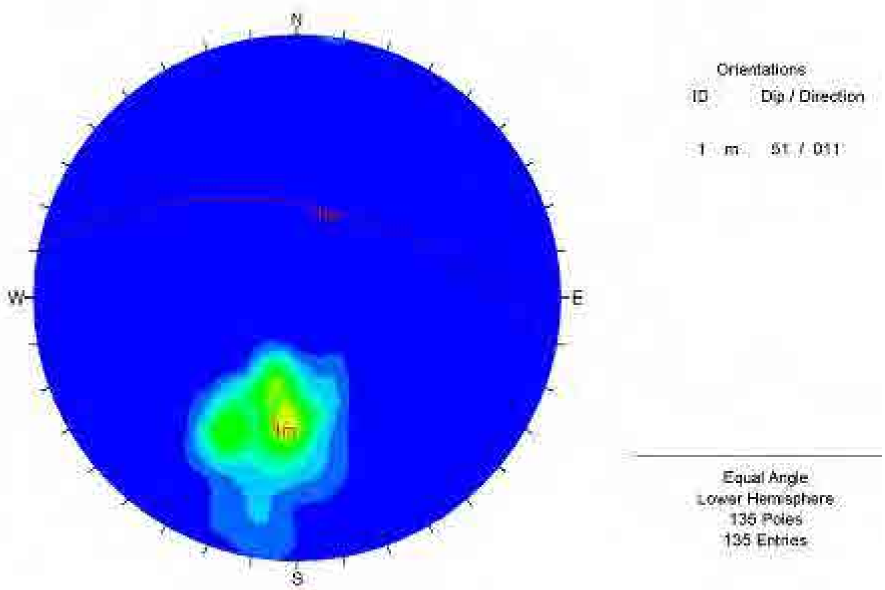

Figure 1.3: Stereographic plots of bedding and foliation from the project area.

Rock mass condition: The Lower Siwaliks are relatively soft rocks and form a subdued topography with smooth hilltops. In the Middle Siwaliks the sandstone–mudstone alternation reaches a thickness of 25 m and more. The overlying Upper Siwaliks are rather loose, and strongly eroded away by gullies and streams. They form sharp and jagged crests. The streams originating from the Upper Siwaliks form alluvial fans, where the rounded pebbles are derived mainly from reworking of the conglomerate beds of the Upper Siwaliks.

The soft and tectonically deformed or crushed slates of the Lesser Himalaya form valleys and smooth spurs. There are many landslides in this zone. The slates are highly weathered and a colluvial mantle is frequently observed.

Weathering: The Lower Siwaliks weather into grey, brown, orange, and red soil. The interbedded grey mudstone is rather soft, and weathers forming polygonal cracks and exfoliation surfaces. The Middle Siwaliks are relatively strong and form cuesta or hogback topography. The multi-storeyed sandstone beds are resistant whereas the following mudstones strata are soft. The Upper Siwaliks weather to yield alluvial fans and gullies. They are strongly eroded by the streams and gullies, especial along the contact between the mudstone and conglomerate beds. The interbedded sandstone beds in the Upper Siwaliks are generally soft but relatively resistant.

Jointing: The Lower Siwaliks are moderately jointed, where joint spacing varies from tens of centimetres to a few metres. There are generally three joint sets and one of them is parallel to bedding. The joints are persistent for a few metres and they are rather rough to wavy. The Middle Siwaliks are distributed mainly in the intake area and the first half of the waterway. The Middle Siwaliks are sparsely jointed (from 30 cm to 3 m apart), with most of the joints being rough and persistent for less than 3 m. But some joints are persistent for tens of metres and form steep counter dip slopes.

Stability conditions: The Lower Siwalik rocks suffer from minor gully erosion and slumping. In the project area they are frequently covered by the colluvial soil. The Middle Siwaliks are generally stable and a few rockslides are observed. The Upper Siwaliks are vulnerable to erosion and many shallow slumps are observed in them. But if the conglomerate is well cemented, the Upper Siwaliks stand as stable ridges with alternating furrows developed on mudstone and sandstone beds.

The flood marks in the Kokhajor Khola were about 3 above the normal flood level. According to the local inhabitants, the river may experience flooding that may reach 5 m in narrow gorges.

Groundwater conditions: Most of the Siwalik terrain is dry after the monsoon season. But the streams coming from the Lesser Himalaya and Higher Himalaya contain some water. Springs and seeps are commonly observed near the riverbed. and the upper parts of the ridges and spurs are dry.

The Lower and Middle Siwaliks are relatively impervious, whereas the poorly-cemented conglomerates of the Upper Siwaliks are quite pervious and their loose interstices are filled with groundwater leading to debris flows.

1.2 Reservoir

The submergence zone (440 m) of the proposed reservoir (Figure 1.4) extends between the Kokhajor Khola, Gatta Khola, and Chau Khola. It inundates mainly Lamibagar, lower part of Majhigaun, Chhotesahan, Anptar, Kokti, and other smaller villages. All these villages lie mainly on the Upper and Middle Siwaliks.

The distribution of rock and soils in the reservoir area is show in Figure 1.5 and the information is summarised in Table 1.1.

Table 1.1: Distribution of rock, soil, and instabilities in the reservoir area and its vicinity (based on field observations and satellite image interpretation).

Material type	Area, sq m	Per cent
Alluvium	9705048	16.6
Residual soil	59061	0.1
Colluvium	12643655	21.7
Bedrock	35896934	61.6
Total	**58304698**	**100.0**
Instabilities	393368	0.67

Geologically, the reservoir area is sound, as there are hardly any weak or vulnerable rocks or zones from which water can seep through. The area is composed mainly of bedrock with minor and shallow alluvial and colluvial deposits. The deep rocky gorge of the Kokhajor Khola and the Chau Khola are ideally suitable for reservoir construction.

The reservoir area may encounter some sedimentation problems from the areas lying to the north, especially around Majhitar and its environs. However, most of the large landslides observed in the area are beyond the water level in the reservoir, and hence their presence has only indirect impact on the reservoir. With proper protection measures, the sediments brought into the reservoir from these instabilities by the streams can be controlled.

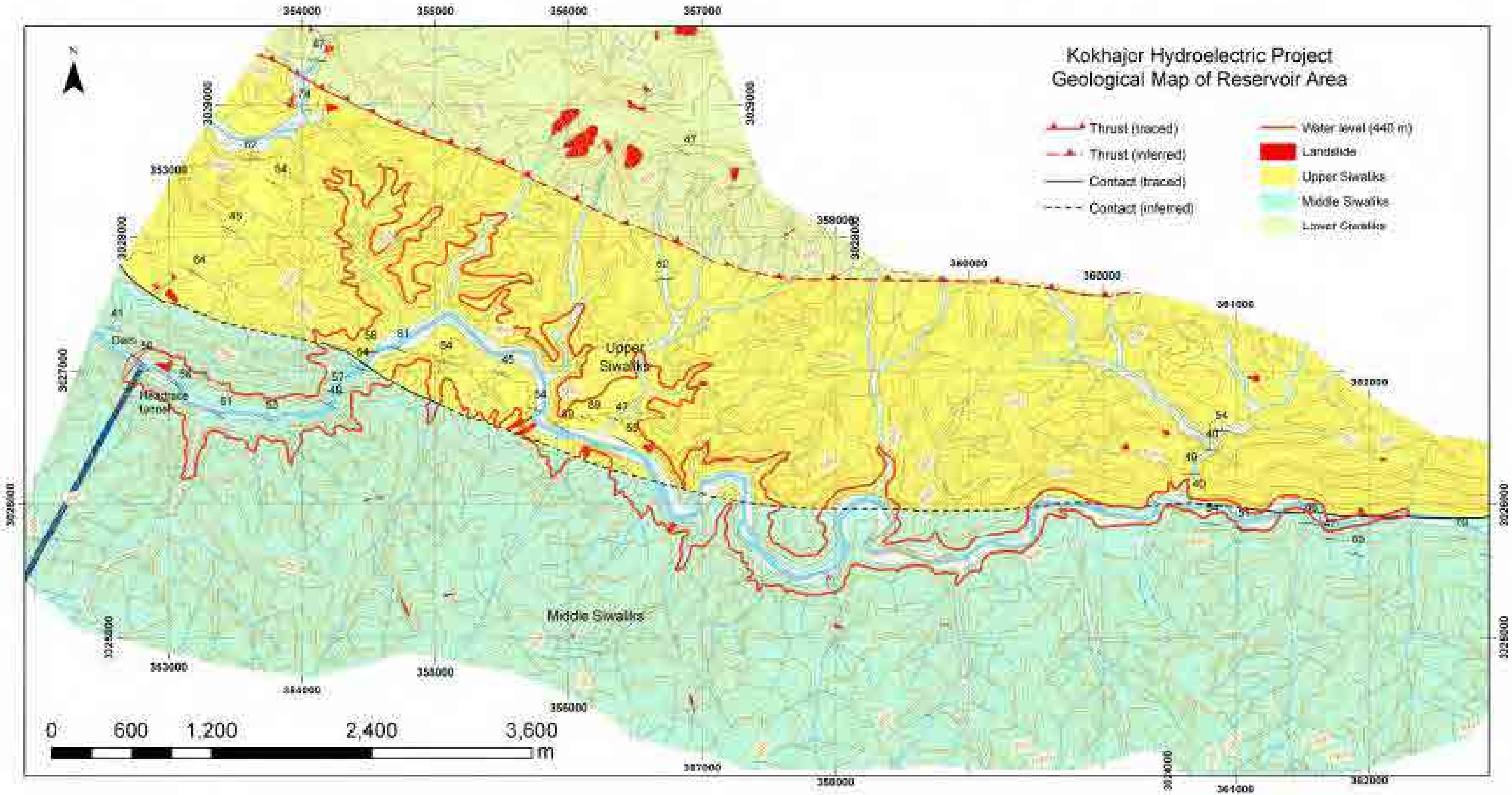

Figure 1.4: Geological map of the reservoir area

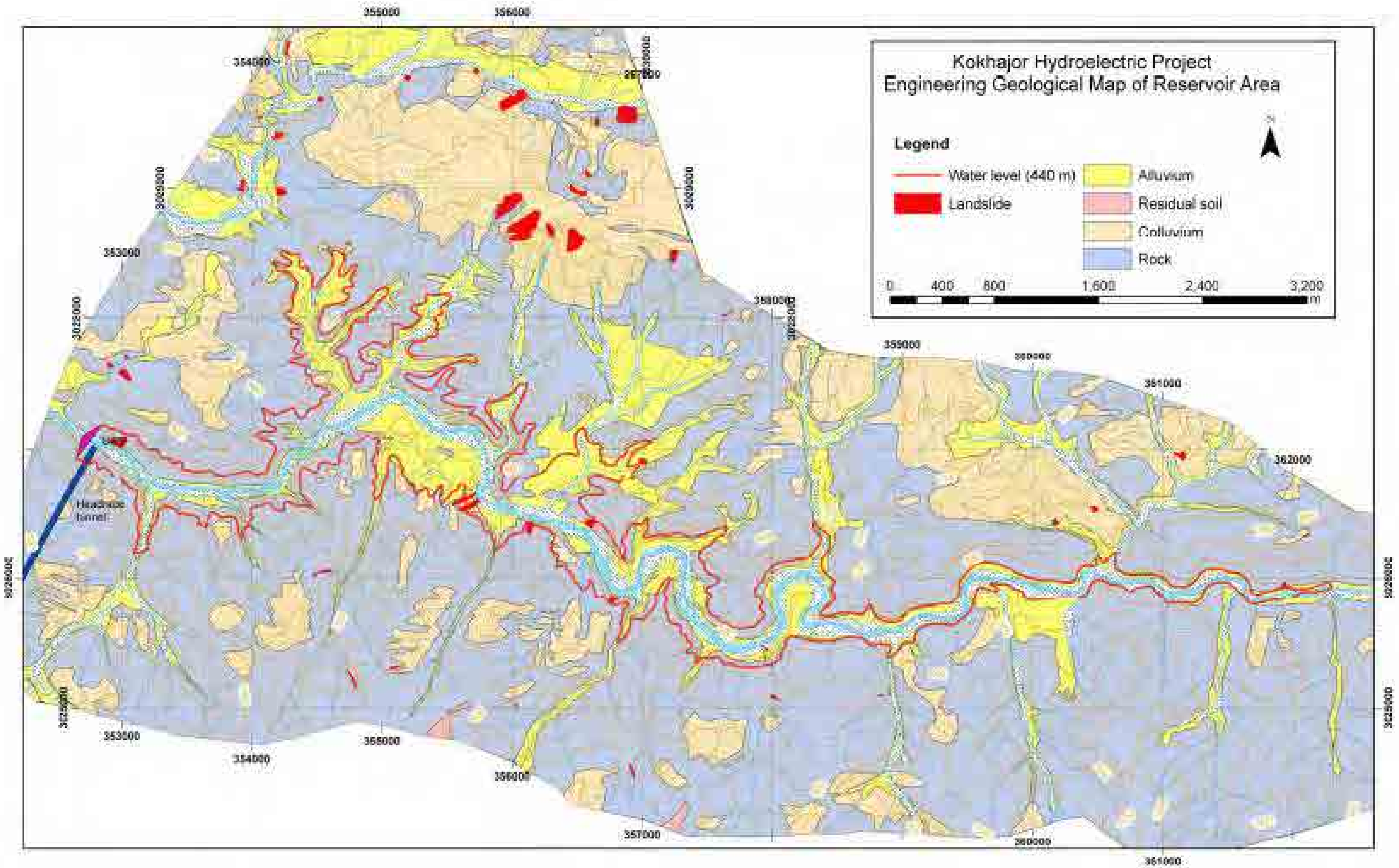

Figure 1.5: Engineering geological map of the reservoir area

1.3 Dam axis

The proposed dam site is located near Sati Ghat in the Kokhajor Khola. The Dam axis passes through the Middle Siwaliks (Figure 1.6, 1.7). The material around the proposed dam axis is made up of very thick-bedded sandstone and mudstone intercalations. The intercalated medium- to coarse-grained sandstone beds and mudstone beds vary in thickness from a few metres to 10 m. The rocks are rather pervious and soft. The beds steeply dip due north. The area is dry and no seepages are springs are found in the vicinity of the dam axis. Since the dam axis and intake lie in the same area, further detaile are given in the chapter of intake.

Generally, the interbedded sandstones and mudstones encountered on the dam axis are inpervious. The dam axis passes through two spurs lying on oppasite banks of the Kokhajor Khola and the rock is sound. The dam foundation seems to be resting on the interbedded sequence of sandstone and mudstone. The rocks are moderately to slightly pervious and need appropriate control measures.

Based on the preliminary assessment, it seems feasible to construct a concrete dam. The rockfill dam or an earth-fill dam will require a great amount of bouders or soil, which is not available at the site.

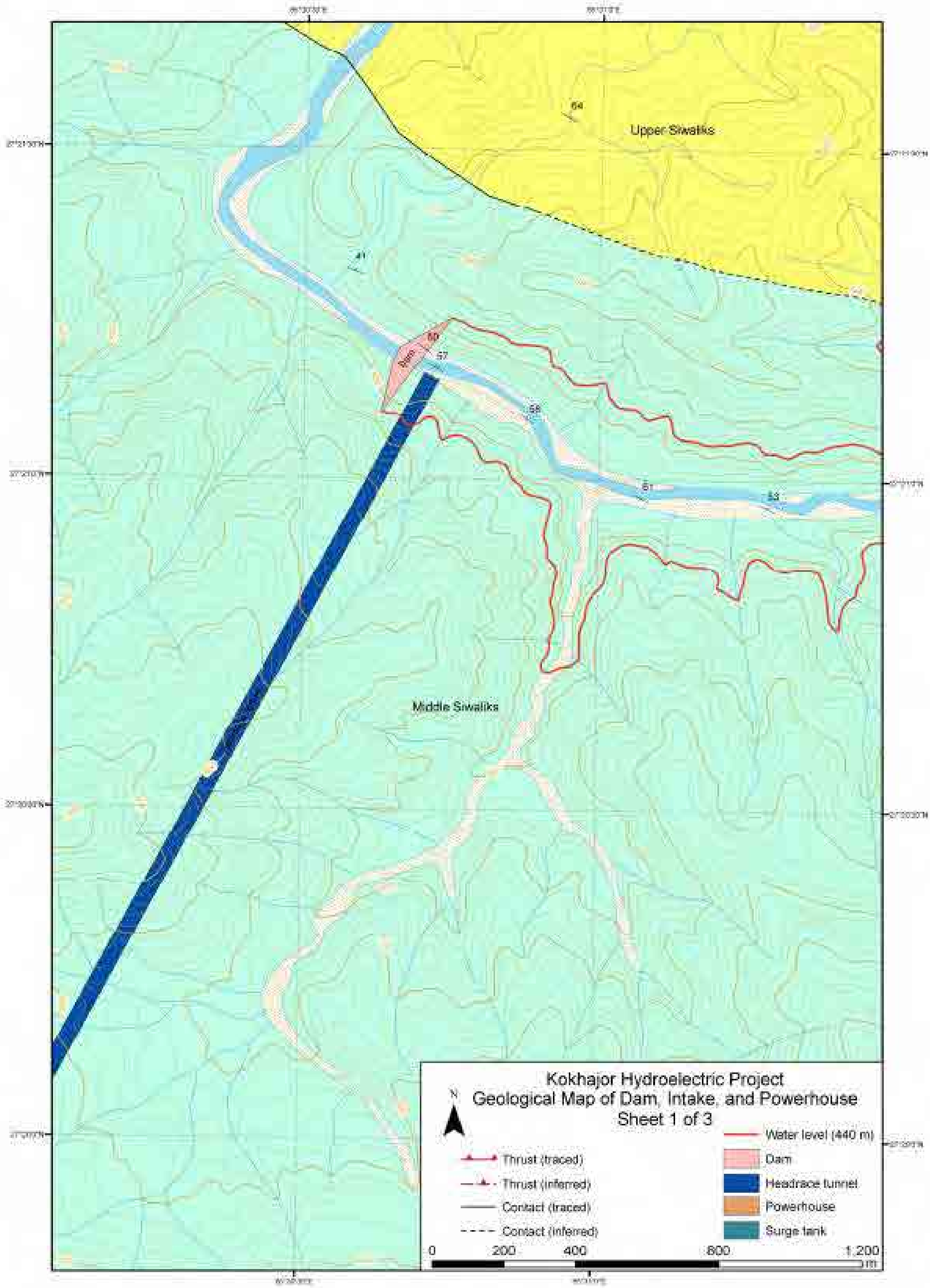

Figure 1.6: Geology of the dam site watereway and powerhouse

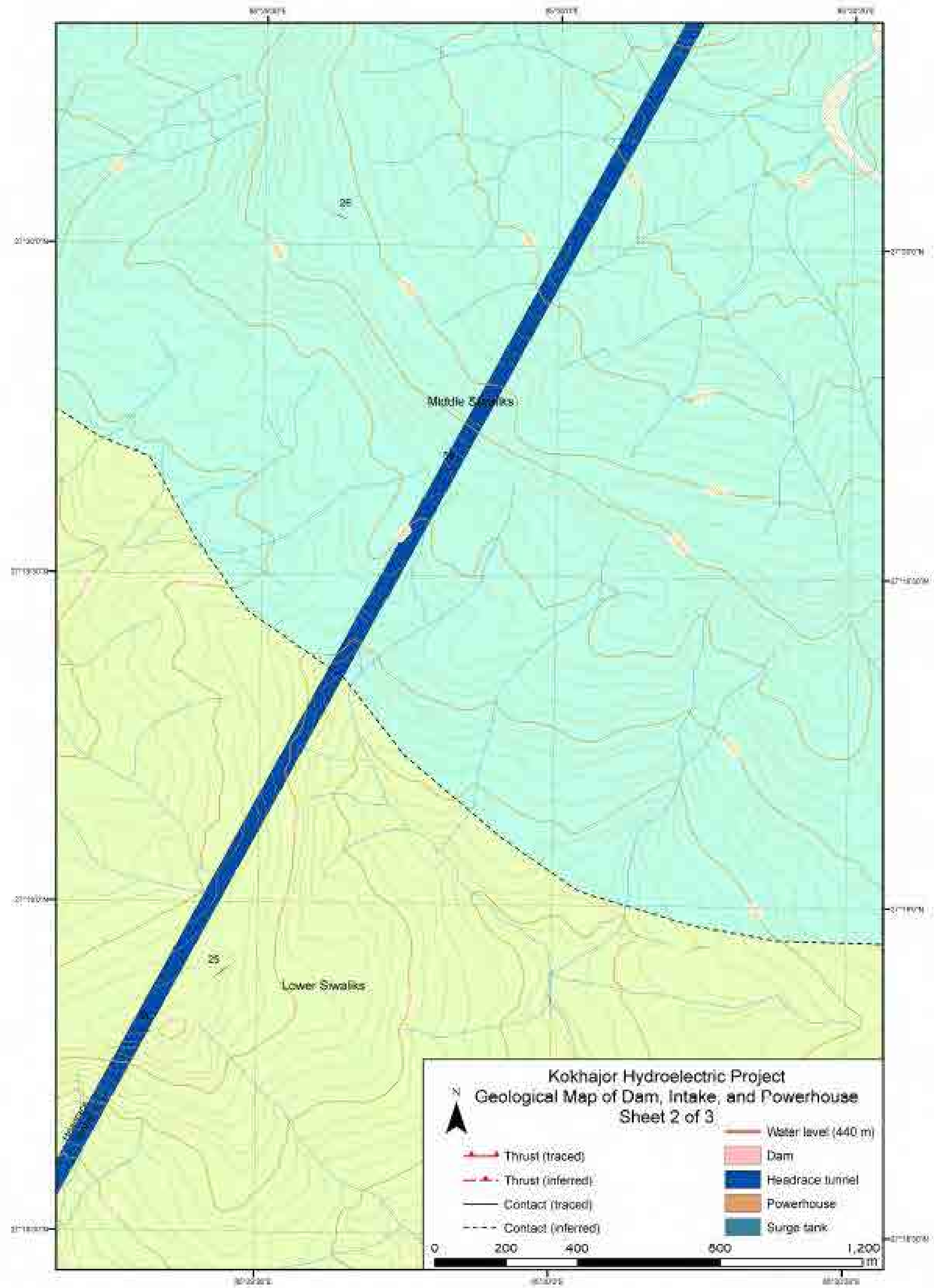

Figure 1.6: Geology of the dam site watereway and powerhouse (continued)

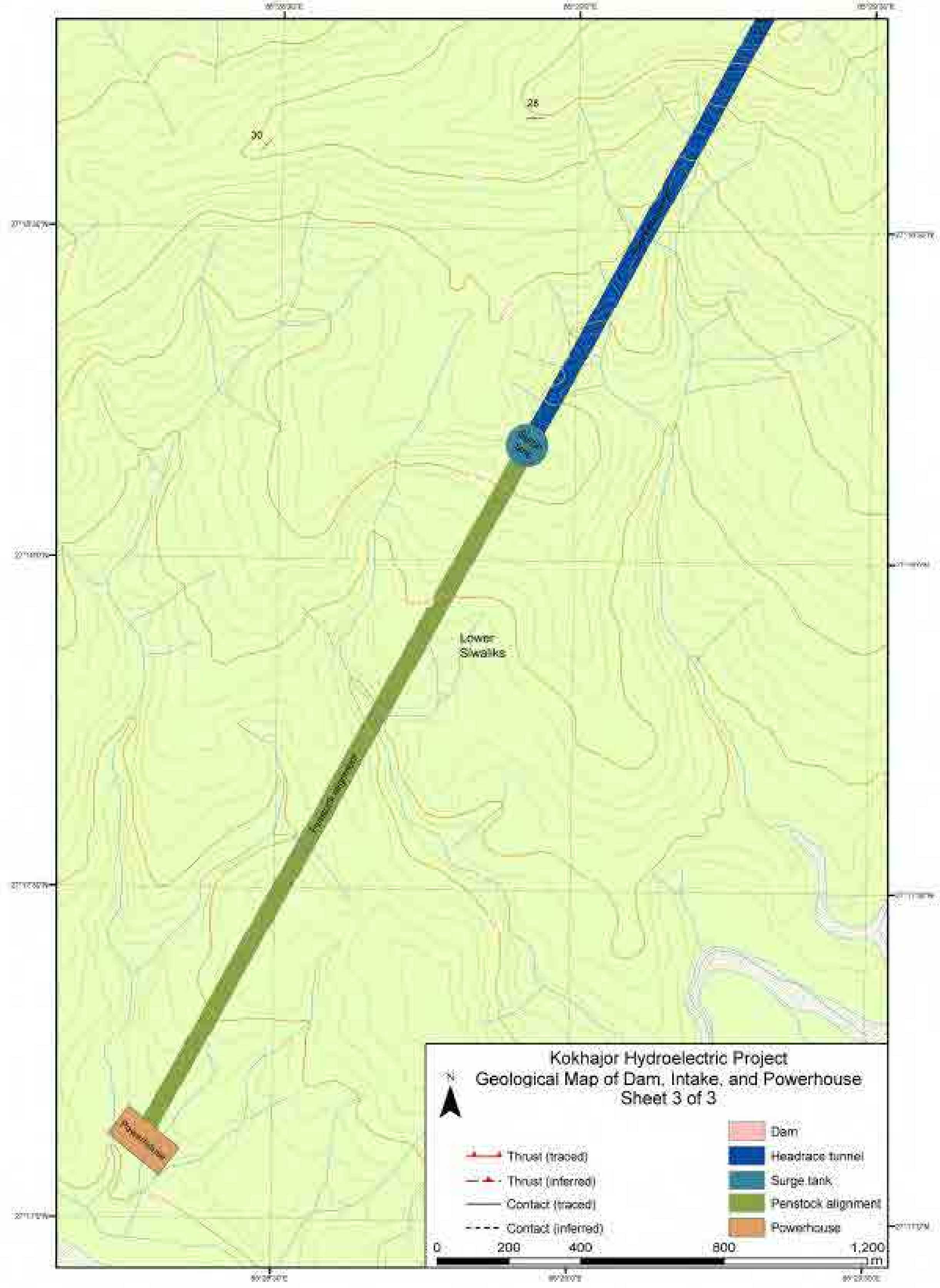

Figure 1.6: Geology of the dam site watereway and powerhouse (continued)

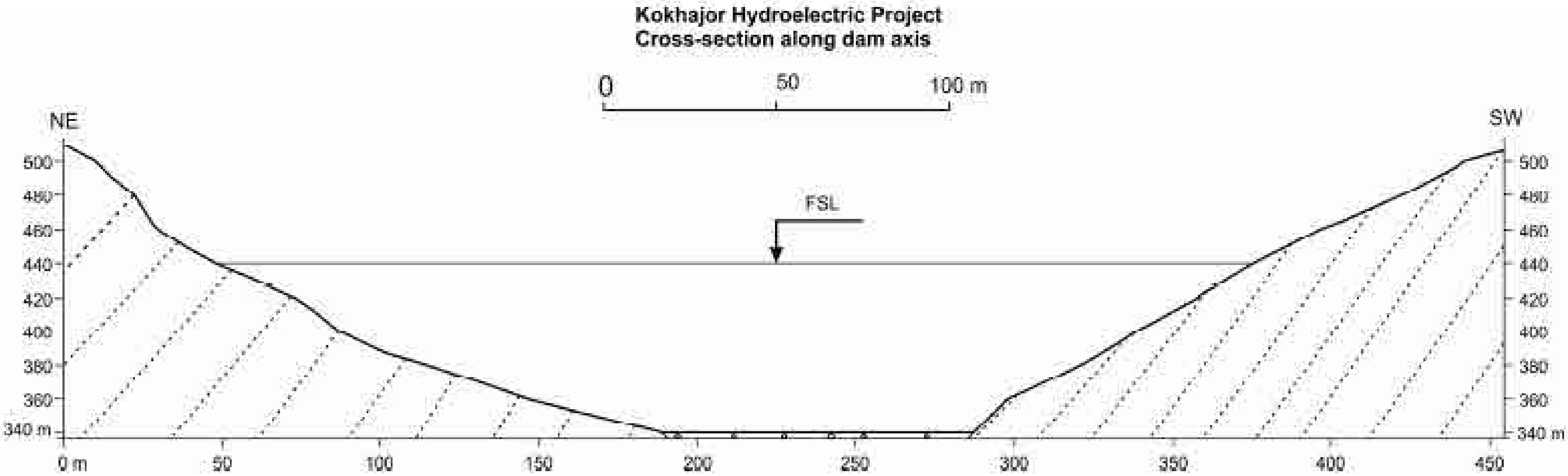

Figure 1.7: Cross section along the dam axis

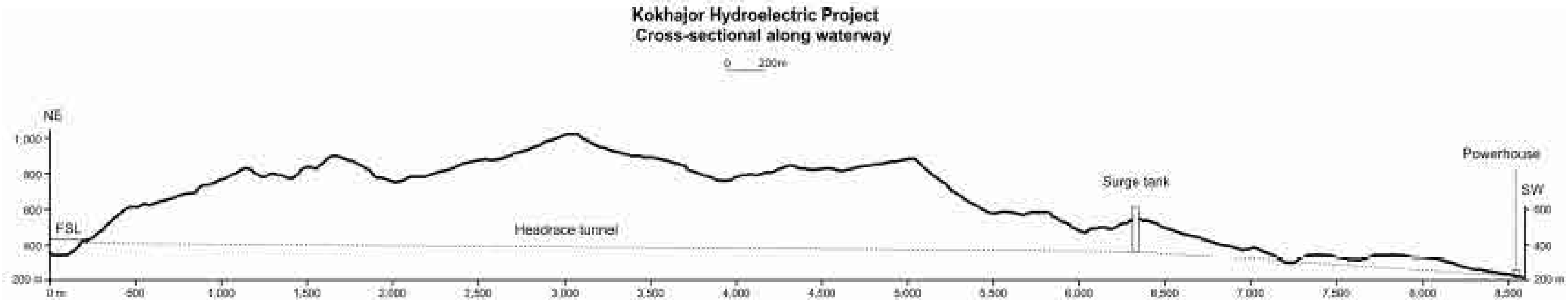

Figure 1.8: Cross section along the waterway

1.4 Waterway

The proposed intake lies in the Middle Siwaliks, on the left bank of the Kokhajor Khola, below Sati Ghat. There are mainly three joint sets (Figure 1.9) controlling the river course and dip of slopes. The steep joint set 3 is making an acute angle with the tunnel alignment. Otherwise, the portal location, and other details are sound and good.

The first 3800 m of the headrace tunnel encounters the Middle Siwaliks. The beds are steep and very thick. The Middle Siwalik sandstones are moderately indurated, moderately strong, and they are interbedded with grey-brown mudstones. The headrace tunnel passes through a maximum overburden of 600 m in the Middle Siwaliks. Hence some precautionary measurers are necessary against squeezing and overbreak.

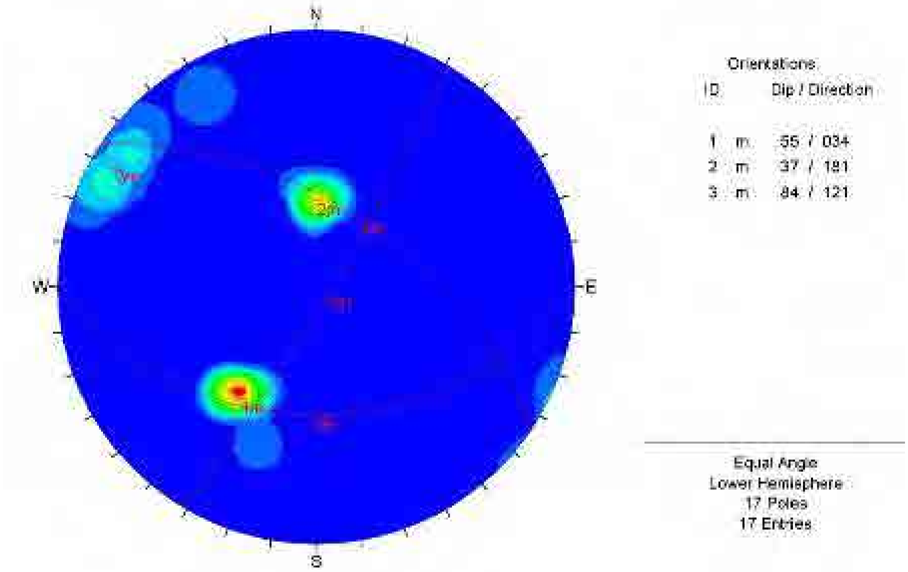

Figure 1.9: Orientation of discontinuities at intake of the Kokhajor Hydroelectric Project.

The south half part of the proposed tunnel alignment (Figure 1.2, 1.8) passes through the Lower Siwaliks for about 2800 m. They are relatively soft rocks and may need appropriate protection measures.

The proposed penstock alignment passes through the spurs and valleys with the Lower Siwalik for about 2000 m. It will encounter mainly residual soil and highly weathered Lower Siwaliks made up of fine sandstone and grey-brown mudstone. The penstock alignment also crosses a few deep gullies and needs some protection measures. It finally arrives at the powerhouse site running on the alluvial terraces of the Bagmati River.

1.5 Powerhouse

The Powerhouse site is located at Sande, on the left bank of the Bagmati River. It is an alluvial terrace resting on the Lower Siwaliks. The alluvium is made up of cobble- to pebble-conglomerate passing into sand and silt. There are mainly two terraces and the proposed powerhouse is lies on the lower terrace. The alluvium is about 10 to 20 m thick and the area is cultivated with paddy. It is a relatively safe location. But the water from the gullies and nearby streams needs to be properly managed.

1.6 Instabilities

The project area is rather stable and has relatively a few instabilities. Most of the landslides are aligned parallel to the main three faults. Apart from these fault-controlled failures, there are some plane rockslides and wedge slides on the Middle and Upper Siwaliks.

The total is of instabilities (including landslides, gullies, and riverbank erosion) within the reservoir and its vicinity (Figure 1.5) mapped in the field or delineated using satellite images is 393368 m2 (or 0.67% of the total area, Table 1.1). Many instabilities are concentrated within the three fault zones (Zones). Since the are surrounded by faults is intensely deformed and crushed, the development of slides, flows, and erosion is very high. However, the large instabilities are located significantly away from the reservoir area.

1.7 Construction materials

The required amount of gravel, sand, and fines is not sufficiently available at the dam site and it is required to bring the material from the Bagmati River and its other tributaries located downstream from the proposed dam site. Sand is abundantly found in the Bagamati River, whereas the boulders of quartzite, sandstone, gneiss, marble, and granite could be utilised for this purpose.

The dam construction will require a significant amount of gravel and sand. But the material is not available at the dam site. But the gneisses, quartzites, and marble boulders in the Bagmati River, about 10 km downstream from the proposed dam can be good sources of the construction material. Similarly, sand is also available on the convex banks and in the median bars of the Bagmati River.

1.8 Further recommendations

The present survey revealed that the reservoir, intake, waterway, and powerhouse sites are sound and appropriate. However, the location of the dam axis needs further investigation, especially regarding the permeability and seepage of partially cemented conglomerate beds. The fault near the north end of the dam axis also requires further detailed assessment.

1.9 GPS survey and photos

The GPS data and photos are separately submitted and the main photos are described below.

Photo 1.1: General view of the Kokhajor Khola near Chakali

Photo 1.2: Large landslide on the left bank of Kokhajor Khola at Anptar

Photo 1.3: Jointed sandstone on the left bank of Kokhajor Khola in intake area

Photo 1.4: Main Boundary Thrust (MBT) exposed at a large landslide near Majhigaun

Photo 1.5: Proposed powerhouse area at Sande. View to N

Table 1.2: Impotant photos

Photo number	***Description***
DSC00351	The upper reach of inundation area by Kokhajor Khola at Lamibagar village viewing towards northwest.
DSC00353	The upper reach of Kokhajor Khola near suspended bridge to Chakali, viewing towards north east
DSC00362	The general northwest view of Kokhajor Khola near Chakali
DSC00364	North dipping sandstone bed on the left bank of Kokhajor Khola near Chakali viewing towards northwest
DSC00367	Suspended bridge over Kokhajor Khola at Gata Khola
DSC00370	Large old rock slide on the very thick pebbly sandstone near suspended bridge to Chakali viewing towards south
DSC00371	Large plane rock slide near suspended bridge over Kokhajor Khola to Chakali viewing towards west
DSC00373	Conglomerate on the left bank of Kokhajor Khola under suspended bridge near Chakali
DSC00375	Large landslide toe near Chakali
DSC00383	West view of Devitar village, Siwaliks to the south and Higher Himalaya to the north
DSC00398	The Main Boundary Thrust (MBT) separating sandstone and mudstone of Siwalik and black slate of Lesser Himalaya to the north at Sola Bhanjyang viewing towards south
DSC00405	Strongly crenulated schist of Higher Himalaya at Sola Bhanjyang
DSC00410	East view of Main Central Thrust (MCT) and Main Boundary Thrust (MBT) at Sola Bhanjyang, where MCT and MBT tend to meet together
DSC00415	South view of inundation area at Anptar
DSC00416	West view of inundation area at Anptar
DSC00420	Sandstone bed exposed on the left bank of Kokhajor Khola at Anptar
DSC00435	Large landslide on the left bank of Kokhajor Khola viewing towards south at Anptar
DSC00440	Large landslide near Dubhigaun village (south west of Anptar) viewing towards west
DSC00444	The riverbed or point bar very useful as construction material near Dubhigaun

DSC00451	Interbedded mudstone and sandstone on the right bank of Kokhajor Khola near Dubhigaun viewing towards south west
DSC00447	About 10cm thick and 15cm long coal seam entrapped within sandstone near Dubhigaun
DSC00453	Steep cliff on the left bank of Kokhajor Khola near intake area
DSC00470	Proposed intake area
DSC00473	Bioturbation on sandstone at the proposed intake area
DSC00476	Jointed sandstone on the left bank of Kokhhajor Khola at intake area
DSC00477	Interbedded mudstone and sandstone at intake area
DSC00504	Landslide of Upper Siwalik on both bank of Chau Khola near Chhote Sahan viewing towards west
DSC00510	Landslide on the left bank of Chau Khola west of Majhigaun village viewing towards northwest
DSC00515	Large landslide near Majhigaun viewing towards northwest
DSC00520	The view of Main Boundary Thrust (MBT) exposed on the large landslide near Majhigaun
DSC00545	The proposed dam site, downstream of suspended bridge at Kokti
DSC00550	The cross-sectional view of interbedded mudstone, sandstone and conglomerate exposed below proposed dam axis on the left bank viewing towards west at Kokti
DSC00552	Left bank view of dam site at Kokti
DSC00554	Rock boulders carried out by Kokhajor Khola around dam site viewing towards west at Kokti
DSC00566	Dam axis view from Bajhgaun
DSC00582	The general course of Kokhajor Khola viewed from Karmidanda
DSC00620	Settlement at Sande, just above proposed powerhouse area
DSC00609	View of Bagmati River below proposed powerhouse area
DSC00624	View of Proposed powerhouse and surrounding area
DSC00631	Thick alluvium just above powerhouse area at Sande
DSC00646	The exact location of Proposed powerhouse area at Sande
DSC00651	North view of Proposed powerhouse area at Sande
DSC00652	The proposed powerhouse area at Sande

Table 1.3: Orientation of joints at the intake area

Waypoint	Strike old	Dip amount	Strike	Dip direction	Dip	Angle	TypeB
421	130	58	130	N	40	58	B
	297	48	117	N	27	48	B
	132	55	132	N	42	55	B
	110	66	110	N	20	66	B
	125	52	125	N	35	52	B
	130	56	130	N	40	56	B
	122	52	122	N	32	52	B
	104	37	104	S	194	37	J1
	97	42	97	S	187	42	J1
	88	30	88	S	178	30	J1
	90	37	90	S	180	37	J1
	80	43	80	S	170	43	J1
	87	35	87	S	177	35	J1
	22	87	22	E	112	87	J2
	60	81	60	E	150	81	J2
	30	82	30	E	120	82	J2
	41	84	41	E	131	84	J2

Table 1.4: Orientation of bedding and foliation in the project area

Waypoint	Strike old	Dip amount	Strike	Dip direction	Dip	Angle	TypeB
51	115	33	115	NE	25	33	B
52	111	36	111	NE	21	36	B
53	114	41	114	NE	24	41	B
54	94	31	94	NE	4	31	B
55	75	42	75	NW	345	42	B
56	73	50	73	NW	343	50	B
57	100	46	100	NE	10	46	B
58	95	42	95	N	5	42	B
59	101	70	101	N	11	70	B
60	102	85	102	N	12	85	B
61			0		wrong	0	
62	96	47	96	N	6	47	B
63	95	46	95	N	5	46	B
64	100	51	100	NE	10	51	B
65	94	54	94	N	4	54	B
66	95	40	95	N	5	40	B
67	88	49	88	N	358	49	B
68	100	40	100	N	10	40	B
69	90	54	90	N	360	54	B
70	95	59	95	N	5	59	B
71			0		wrong	0	
72	104	42	104	NE	14	42	B
73	94	37	94	N	4	37	B
74	96	55	96	N	6	55	B
367	85	53	85	N	355	53	B
368	94	87	94	N	4	87	B
369	97	84	97	N	7	84	B
370			0		wrong	0	
371	120	67	120	NE	30	67	B
372	75	46	75	NW	345	46	B
373	70	65	70	NW	340	65	B
374	71	31	71	NW	341	31	F
375	85	43	85	NW	355	43	F
376	100	38	100	NE	10	38	F
377	58	36	58	NW	328	36	F
378	85	46	85	NW	355	46	F
379	70	54	70	NW	340	54	F
380	80	67	80	NW	350	67	B
381			0		wrong	0	
382	80	64	80	NW	350	64	B
383	95	76	95	N	5	76	B
384	83	89	83	N	353	89	B
385	120	61	120	NE	30	61	B
386			0		wrong	0	
387	80	81	80	NW	350	81	B
388	110	75	110	NE	20	75	B
389	99	86	99	N	9	86	B
390	84	69	84	N	354	69	B
391	96	50	96	N	6	50	B
392	90	69	90	N	360	69	B
393	92	49	92	N	2	49	B
394	84	68	84	N	354	68	F
395	106	65	106	N	16	65	F
396	87	60	87	N	357	60	F
397	105	34	105	NE	15	34	F
398	82	47	82	N	352	47	F

Waypoint	Strike old	Dip amount	Strike	Dip direction	Dip	Angle	TypeB
399	102	45	102	N	12	45	F
400	111	50	111	N	21	50	F
401	72	40	72	N	342	40	F
402	94	63	94	N	4	63	B
403	94	52	94	N	4	52	B
404	123	47	123	NE	33	47	B
405	124	47	124	NE	34	47	B
406	87	52	87	N	357	52	B
407	115	89	115	NE	25	89	B
408	120	65	120	NE	30	65	B
409	120	47	120	NE	30	47	B
410	115	89	115	NE	25	89	B
411	108	54	108	NE	18	54	B
412	110	45	110	NE	20	45	B
413	97	64	97	N	7	64	B
414	110	61	110	NE	20	61	B
415	95	58	95	N	5	58	B
416	107	54	107	N	17	54	B
417	95	57	95	N	5	57	B
418	116	49	116	NE	26	49	B
419	115	53	115	NE	25	53	B
420	120	61	120	NE	30	61	B
421	130	58	130	N	40	58	B
422	120	57	120	NE	30	57	B
423	127	50	127	NE	37	50	B
424	110	41	110	NE	20	41	B
425			0		wrong	0	
426	120	64	120	NE	30	64	B
427	115	45	115	NE	25	45	B
428	118	54	118	NE	28	54	B
429	90	62	90	N	360	62	B
430	100	74	100	N	10	74	B
431	94	47	94	NE	4	47	B
432	97	57	97	N	7	57	B
433	105	74	105	N	15	74	B
434	95	38	95	N	5	38	F
435	97	70	97	N	7	70	F
436	76	34	76	N	346	34	F
437	98	55	98	N	8	55	F
438	66	40	66	NW	336	40	F
439	80	52	80	N	350	52	F
440	79	57	79	N	349	57	F
441	124	48	124	NE	34	48	F
442	109	31	109	N	19	31	F
443	101	38	101	N	11	38	F
444	94	34	94	N	4	34	F
445			0		wrong	0	
446	95	52	95	N	5	52	F
447	125	42	125	NE	35	42	F
448	138	10	138	NE	48	10	F
449	115	25	115	NE	25	25	F
450	110	37	110	NE	20	37	F
451	70	41	70	NW	340	41	F
452	110	34	110	N	20	34	B
453	140	59	140	NE	50	59	B
454	103	49	103	N	13	49	B
455	116	27	116	NE	26	27	F

Waypoint	Strike old	Dip amount	Strike	Dip direction	Dip	Angle	TypeB
456	290	30	110	N	20	30	F
457	97	30	97	N	7	30	B
458	106	79	106	N	16	79	F
459	117	73	117	N	27	73	B
460	115	63	115	N	25	63	B
461			0		wrong	0	
462	114	59	114	NE	24	59	B
463			0		wrong	0	
464	115	59	115	NE	25	59	F
465	104	40	104	NE	14	40	B
466	99	62	99	N	9	62	B
467	110	66	110	N	20	66	B
468	130	75	130	NE	40	75	B
469	125	57	125	NE	35	57	B
470	118	65	118	N	28	65	B
471	118	58	118	NE	28	58	B
472	104	62	104	N	14	62	B
473	116	61	116	N	26	61	B
474	103	56	103	NE	13	56	B
475	125	58	125	NE	35	58	B
476	112	39	112	NE	22	39	B
477	117	61	117	N	27	61	B
478	115	26	115	N	25	26	B
479	87	50	87	N	357	50	B
480	53	24	53	NW	323	24	B
481	95	28	95	N	5	28	B
482	86	28	86	N	356	28	B
483	45	30	45	NW	315	30	B
484	177	31	177	W	267	31	B
485	164	24	164	W	254	24	B
486	170	37	170	SW	260	37	B

Table 1.5: Geological Study Team Members and Itinerary of the Field Visits

Name of Project	District	Date of field visit	Name of the Geologlist	Investigation method
Kokhajor	Kavrepalanch owk	29h September - 8th October, 2012	Dr. Megh Raj Dital Mr. Narayan Adhikari Mr. Santosh Adhikari	Geological reconnaissance survey

Annex 3: Geological Survey Report

Sun Koshi No.3 (E-17)

Table of Contents

Introduction

This Report deals with the engineering geological investigations in the Sun Koshi No.3 hydroelectric dam projects. This project area was surveyed by Dr. Kamala Kant Acharya, Mr. Baburam Gyewali and Mr. Laxman Subedi between 8 and 14 July 2012. Geology and engineering geology of this project are summarized below.

1 Sun Koshi No.3 Project

The Sunkoshi HEP is located about 200 km east of Kathmandu in the Sindhupalchowk and Ramechhap districts of central Nepal. The project utilizes water from Sunkoshi, Indrawati, Cha Khola, Jhiku Khola, Chauri Khola and other tributaries. The Dam site is located at about 500 m downstream from the confluence of the Chauri Khola and Sunkoshi River. Water ways passes along the left bank of the Sunkoshi River and Powerhouse is located at the terrace about 700 m downstream from the dam site. The reservoir and headworks area of the project can be accessed by Kodari highway, 0 kilo–Melamchi highway and other local foot trails. Fieldwork was carried out for five days. During the field work primary geological data was collected throughout the study area. The location points are presented in Table 1.1 and the major attitude of bedding/foliation are presented in Table 1.2. The topographic map showing the observation points is given in Annex 1.

1.1 Geology of project area

Geologically, the project area lies in the Lesser Himalayan Zone. According to Stöcklin and Bhattarai (1977) the project area consists of the Kuncha Formation and the Benighat Slate of the Nawakot Complex (Figure 1.1). The Kuncha Formation consists of gritty phyllite and medium grained to gritty quartzites. The proportion of quartzite and phylllite varies according to startigraphic position.The Benighat Slate consists of laminated carbonaceous slate with frequently occurring carbonate bands named as Jhiku Carbonate.
Geological map of the project area is shown on Figure 1.2.

Lithology: The Precambrian rocks constituting the Sunkoshi area are represented by phyllites, quartzites, slate and carbonate rocks. The rocks exposed in the project area are thin-to thick-banded medium- to coarse-grained, light grey to white quartzites with partings of schist and thin to medium bands of gritty, greenish grey chlorite schist. These rocks belong to the Kunchha Formation of the Lesser Himalaya. Laminated, dark grey to black, graphitic slates with thick-to very thick-bedded grey siliceous to dolomitic limestone of the Benighat Slates are common in the middle part of the reservoir. The lower part of the reservoir, dam axis and the powerhouse area lies in the Kuncha Formation with a graditional contact, the Kuncha Formation passes into the Benighat Slate. The upper reaches of the reservoir again consists of the Kuncha Formation which thrust over the Benighat Slate. The thrust separating the Benighat Slate in the south and the Kuncha Formation in the north passes along the Indrawati River. The rocks of the area show gentle eastward plunging series of fold.
Quaternary deposits: Alluvial deposits are found on the alluvial terraces of the Indrawati, Sunkoshi, Cha Khola, Jhiku Khola, Chauri Khola and their main tributaries. Alluvial terraces formed by the Indrawati River are so large and are up to three stages. The colluvial deposits predominate on upper moderately steep to gentle slopes and spurs. Some part of the area, especially, along the local road from Dolalghat to Sipaghat thick (up to 10 m) residual soil is observed.

Rock mass condition: The pelitic rocks like slate and phyllite are relatively soft rocks and form a subdued topography with smooth hilltops. While rocks like quartzite and carbonate rocks are comparatively strong. In the project area, these pelitic rocks occur in alternating pattern with relatively stronger rocks like quartzite and limestone. The phyllite found in the Kunchha Formation is relatively stronger than the slate found in the Benighat Slate.

Weathering: Water and air are the main sources of weathering. Apart from them, sunshine (temperature variation) has also played a significant role in weathering of quartzites. The overall weathering depth in rocks reaches up to 5 m and sometimes more than that.
Long-term weathering of resistant quartzite bands has resulted into the widespread distribution of talus cones and debris flow fans. The rounded quartzite blocks and boulders also constitute the alluvial terraces. Weathering of quartzite has developed colluvial soils on the middle slopes. The weathered phyllite yield finer colluvial soil and residual soil on ridges. The weathering of slate forms black colluvial soil.

Jointing: The rocks of the area are moderately jointed consisting three sets of joints with random joints.

Stability conditions: the project area comprises maximum colluvium, so the rate of soil erosion is high. Minor slides on the colluviums along the major rivers and tributaries are common. Few minor rock slides are also observed especially in phyllite and slate. Except the minor slide, no major slides are observed in the project area.

Groundwater conditions: The fieldwork was carried out during the monsoon period, so a large number of springs and seeps were observed near the riverbed whereas the upper parts of the ridges and spurs also contain some springs and seeps. The number of springs are larger in the Benighat Slate than on the Kunchha Formation. All of the major rivers of the project area are perennial whereas minor gullies are seasonal. The quartzite and phyllite are quite impervious and the dam constructed on them or the tunnel passing through them should not pose any serious water ingress problems.

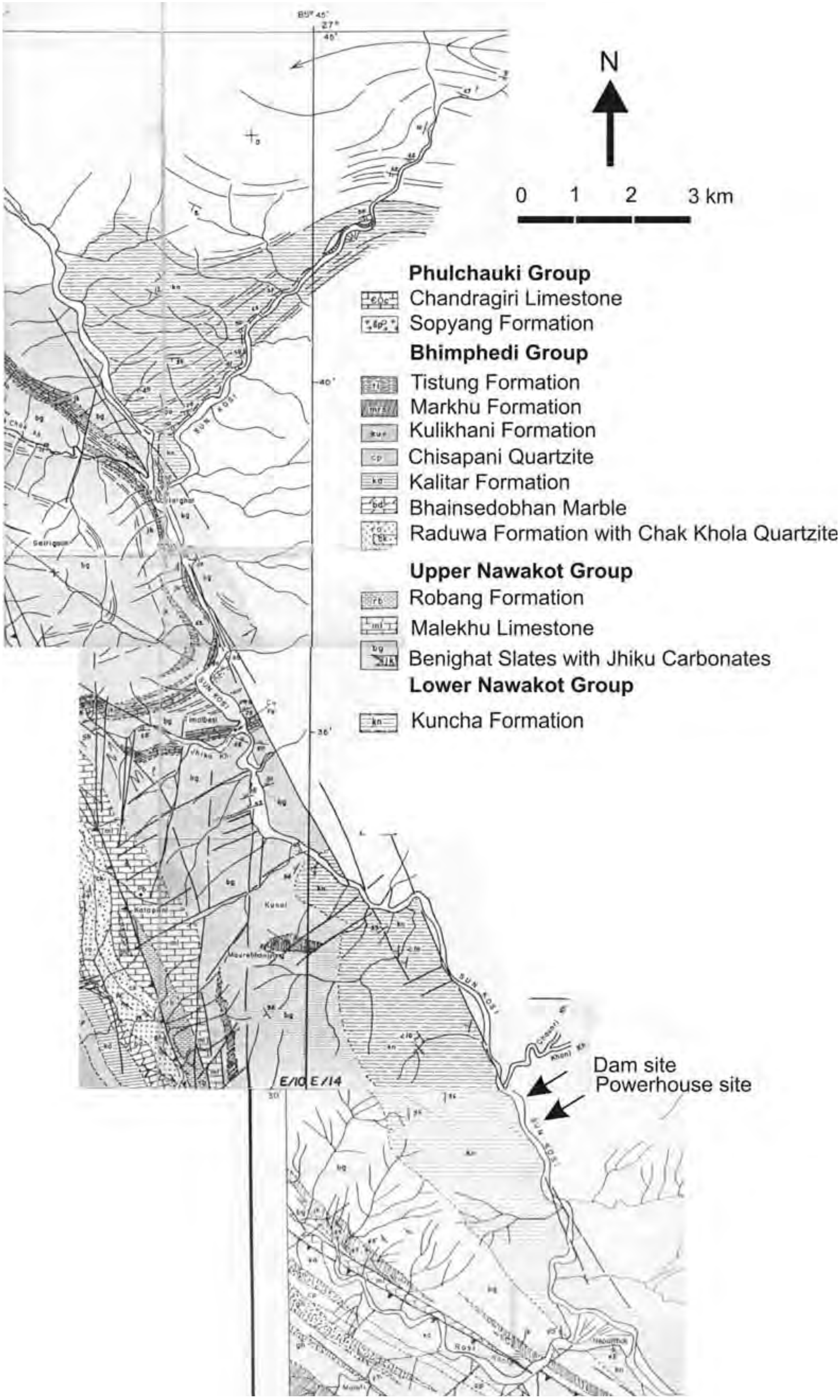

Figure 1.1: Geological map of the project area (after, Stöcklin and Bhattarai, 1977)

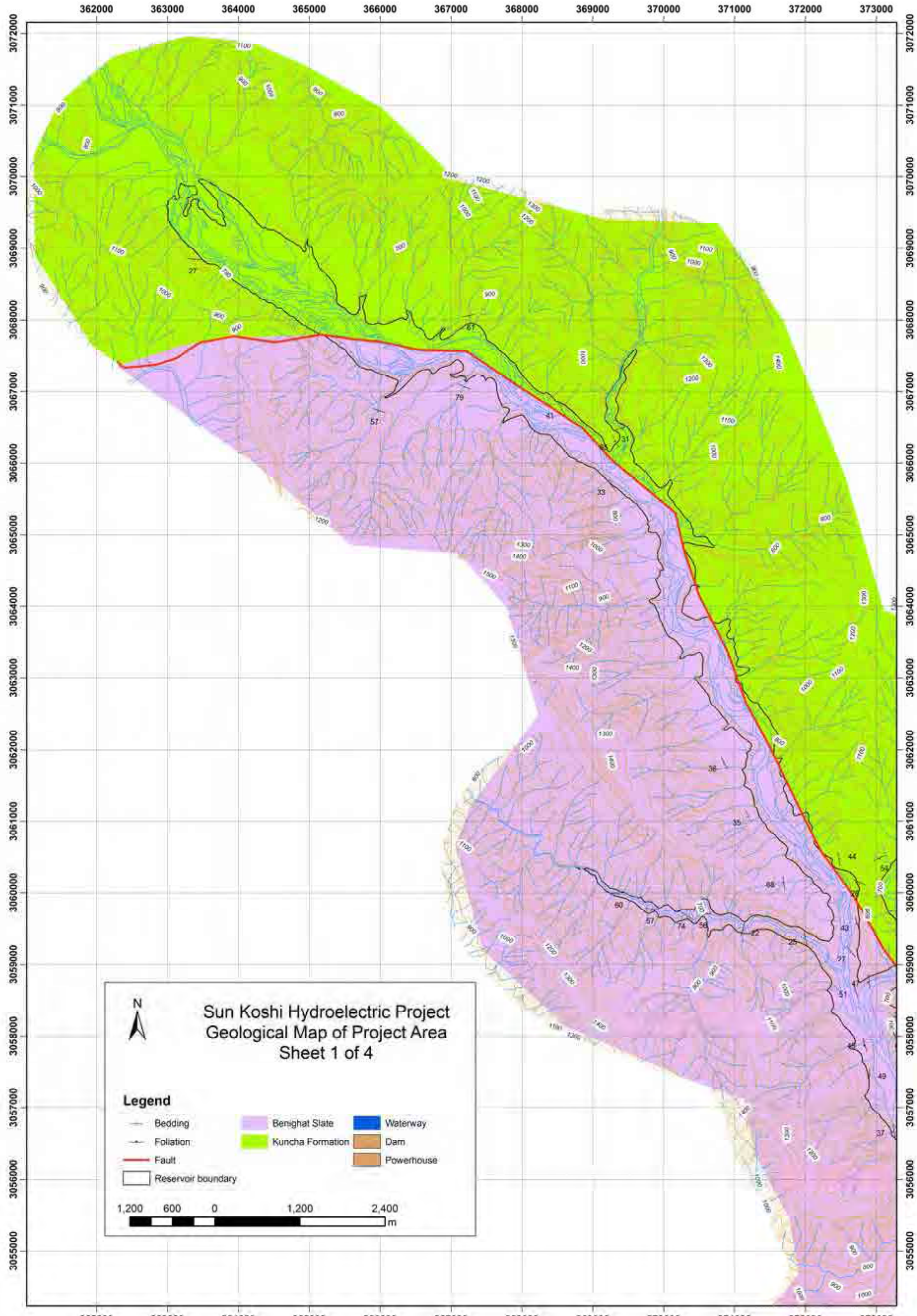

Figure 1.2: Geological map of the project area

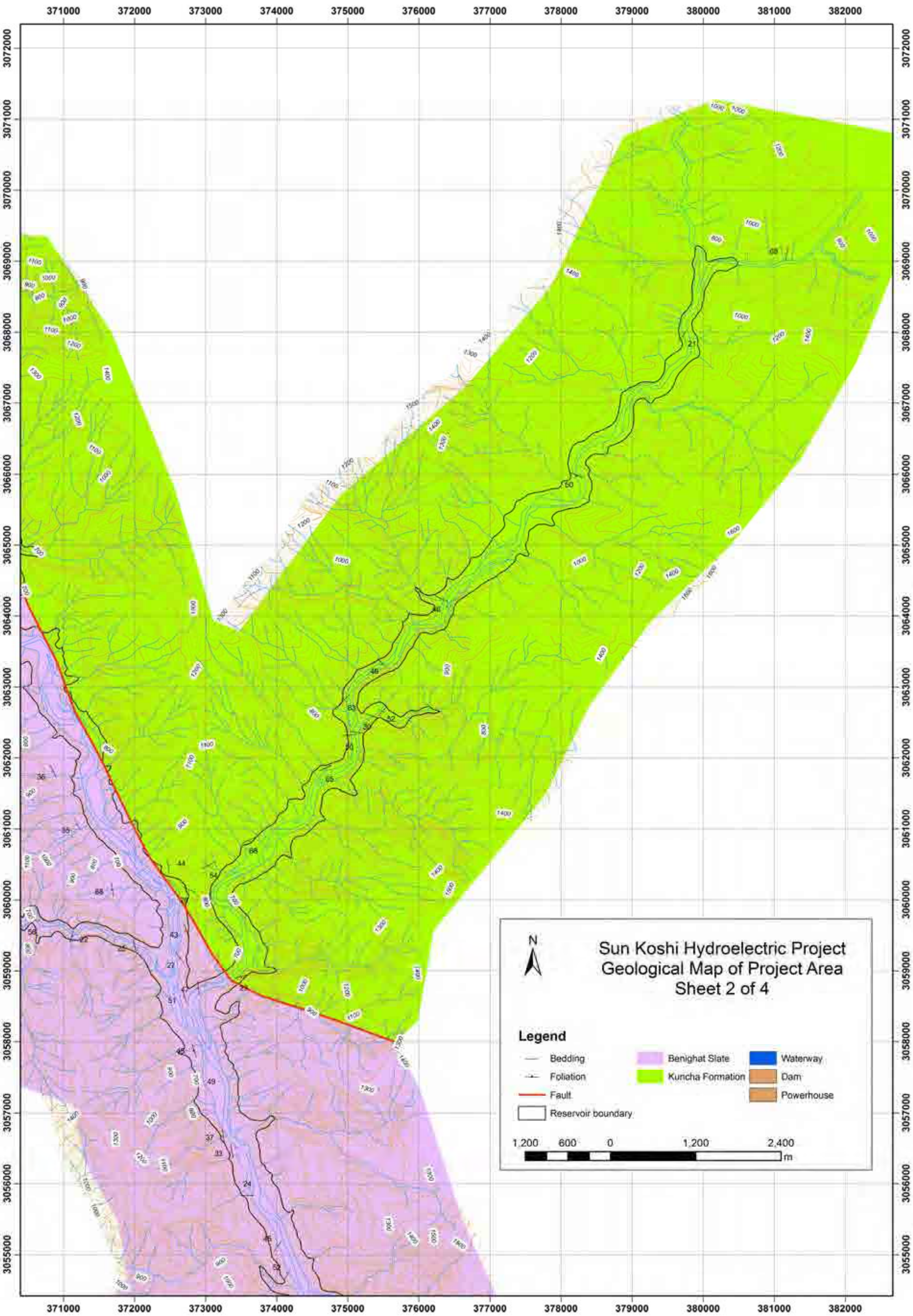

Figure 1.2: Geological map of the project area (contd.)

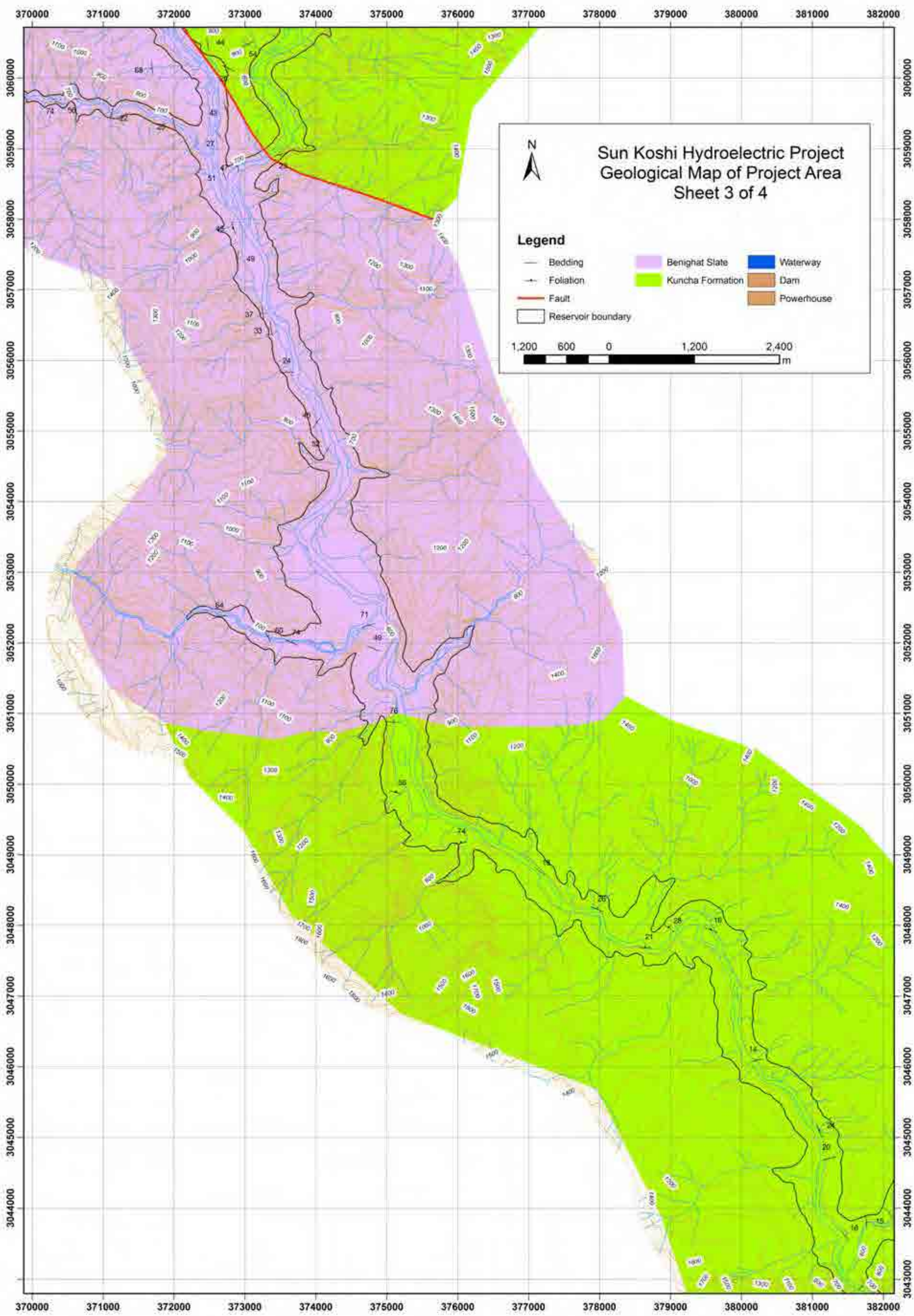

Figure 1.2: Geological map of the project area (contd.)

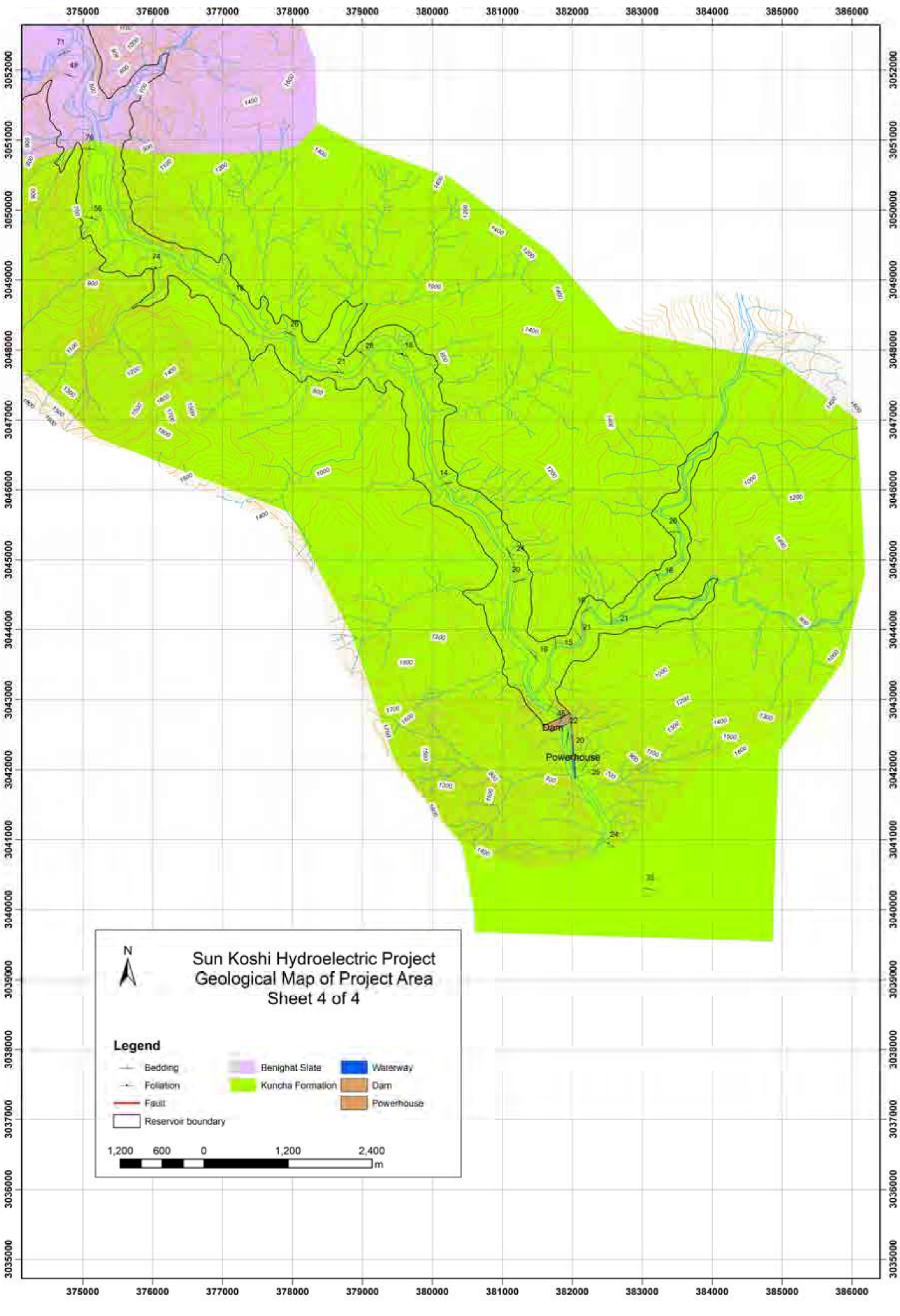

Figure 1.2: Geological map of the project area (contd.)

1.2 Reservoir

The water level (700 m) in the proposed reservoir extends up to downhill of the Dhaireni village in the Cha Khola, Near to Bhimtar of the Jhyari Khola, South of Sipaghat in the Indrawati River, Kothe in the Sunkoshi River and Simle and bhadaure in the Balephi Khola.

The engineering geological map of the reservoir and its surrounding areas is presented in Figure 1.3.

Except the soil erosion from the huge volume of colluviums no other significant weak or vulnerable zones leading to dam collapse or large failures obstructing the reservoir are observed. The fault passing along the Indrawati River show narrow shear zone along the newly constructing Sahid Road from Bodgaun to Bisdevtar (Figure 1.4) but no significant landslide and other mass wasting phenomenon are observed on the surface.

The area to be under water consists of bedrock, alluvial terraces, colluvium and minor instabilities. There will be significant sediment transport from the major rivers, especially from the Indrawati River which passes along the fault. Hence some check dams and other sediment retention structures are required to prevent the sediment inflow in the reservoir.

Water tightness: As there is no chance to flow water of the reservoir in other drainage basins, the reservoir is perfectly water tight.

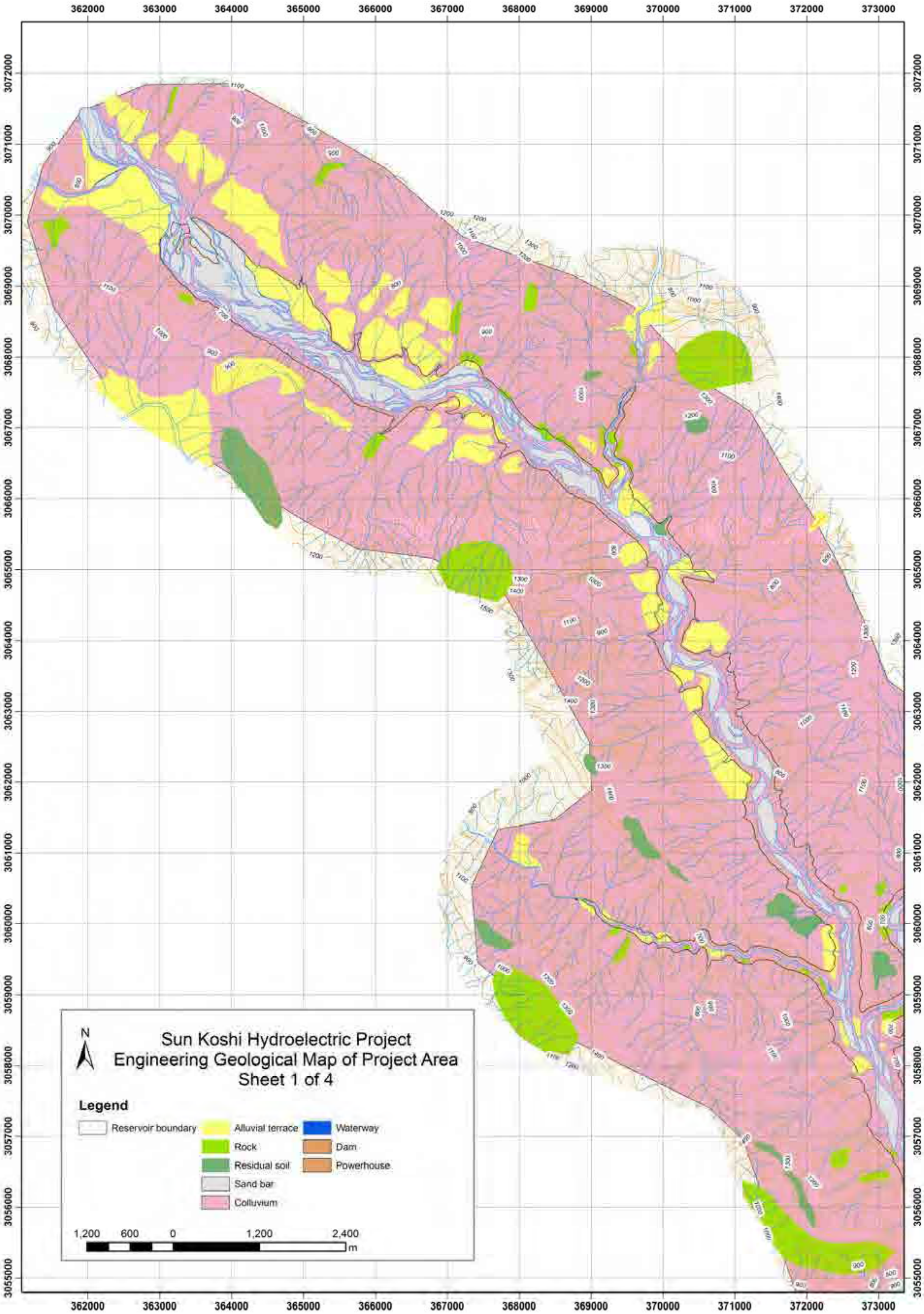

Figure 1.3: Engineering geological map of project area

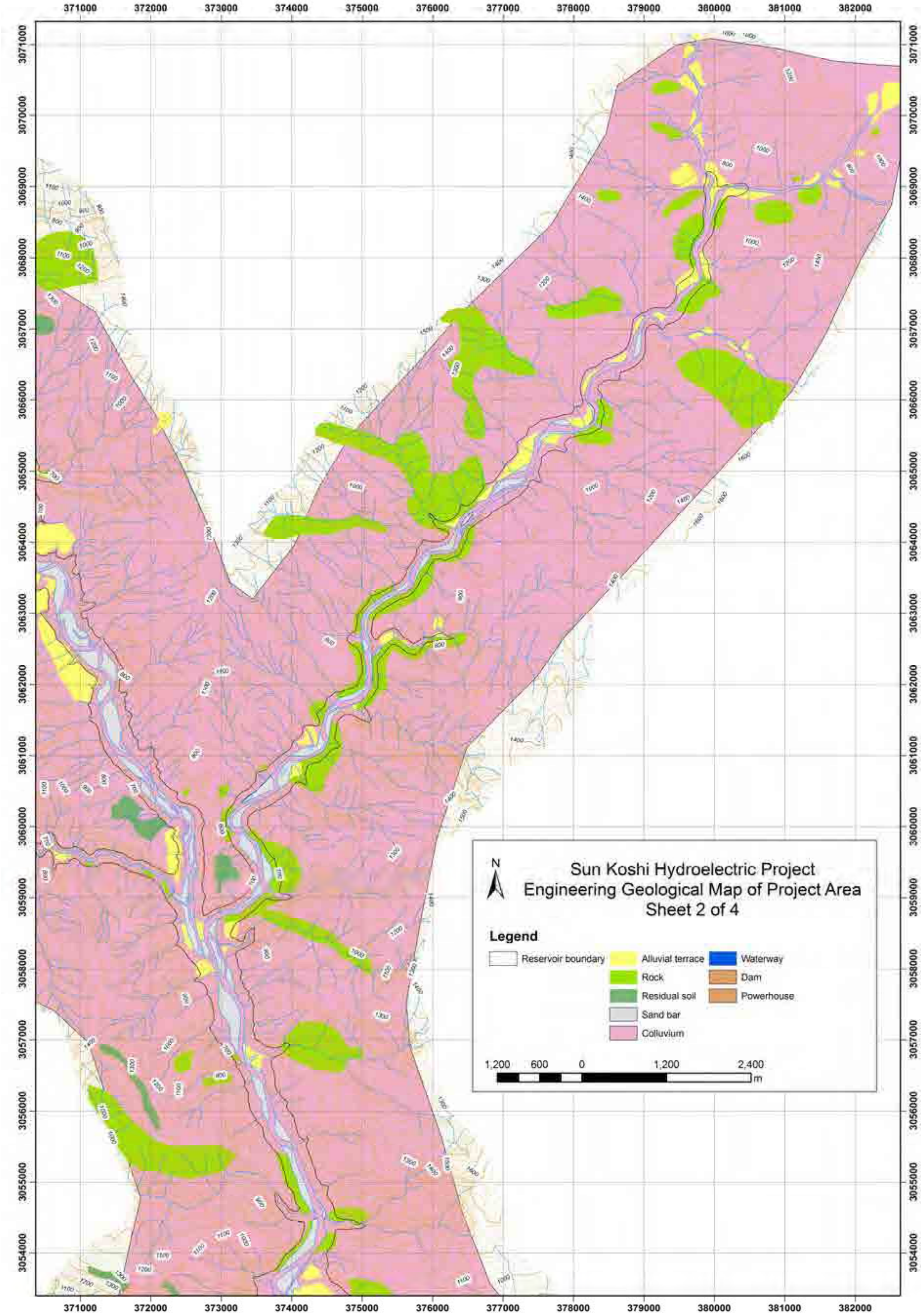

Figure 1.3: Engineering geological map of project area (contd.)

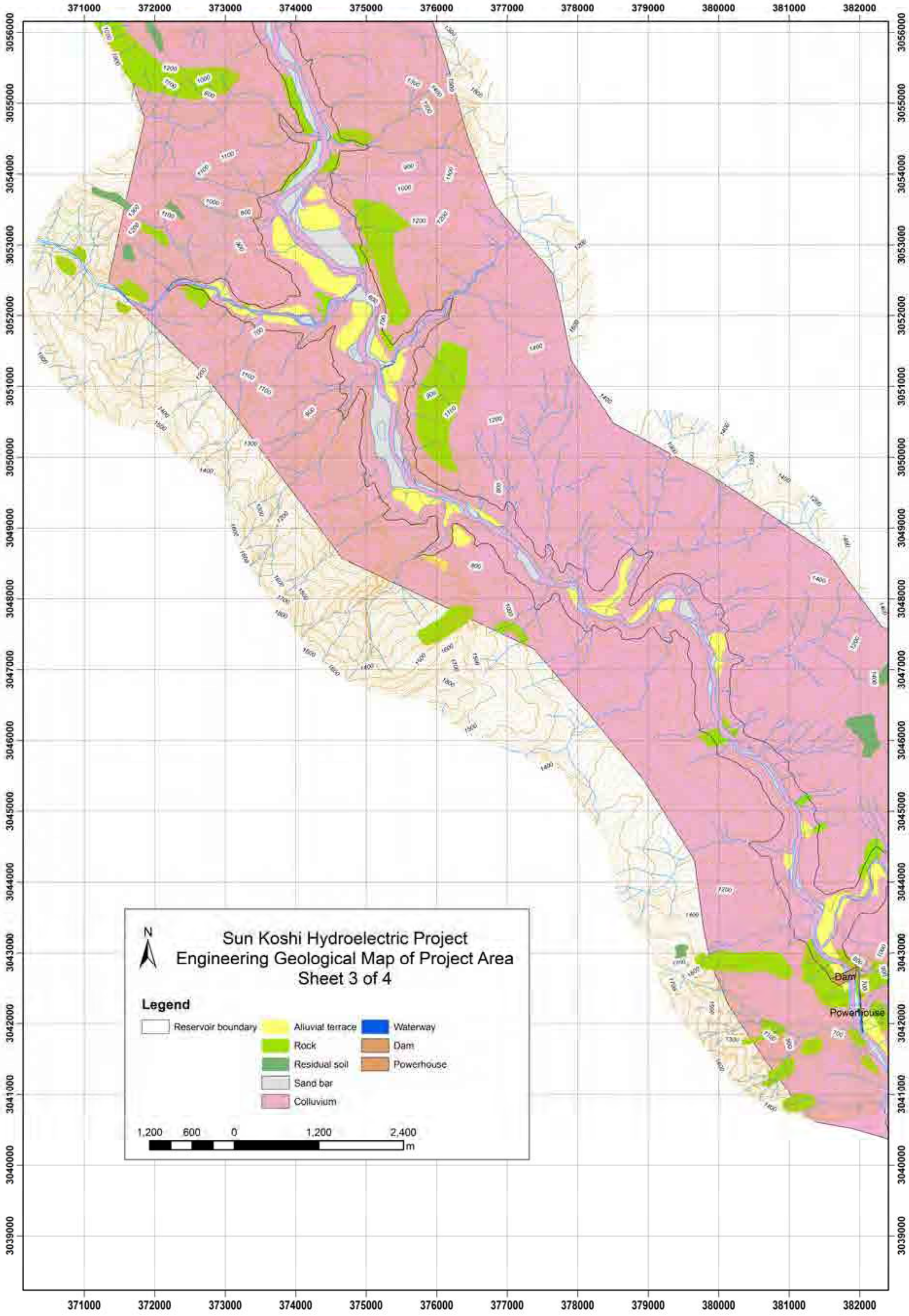

Figure 1.3: Engineering geological map of project area (contd.)

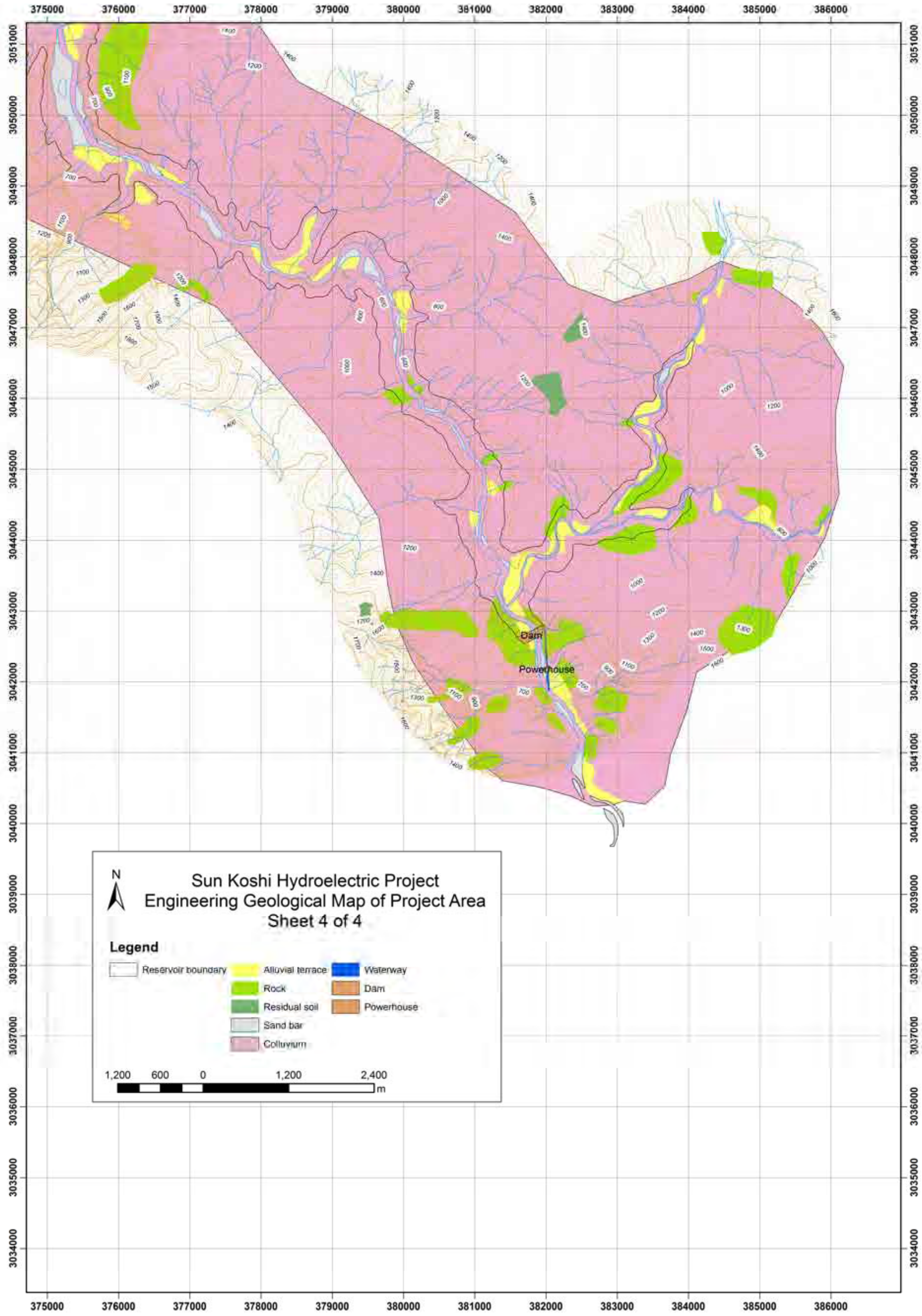

Figure 1.3: Engineering geological map of project area (contd.)

Figure 1.4: Shear zone observed on the left bank of the Indrawati River, at location 259.

1.3 Dam axis

The Dam site is located at about 500 m downstream from the confluence of the Chauri Khola and Sunkoshi River. The proposed dam axis (Figures 1.5 and 1.6) seems sound on the basis of rock type and nature of discontinuities. At the dam site, the rock is represented by medium-to thick-bedded medium-to coarse-grained light grey to white quartzite with partings and thin bands of phyllite. The dam foundation and the area around the dam axis are impervious and do not pose any serious threat of seepage. Three sets of joints are observed at the dam site (Figure 1.7). As the proposed dam axis lies in quartzite, the area shows high water tightness. Cross-section along the dam is shown in figure 1.8.

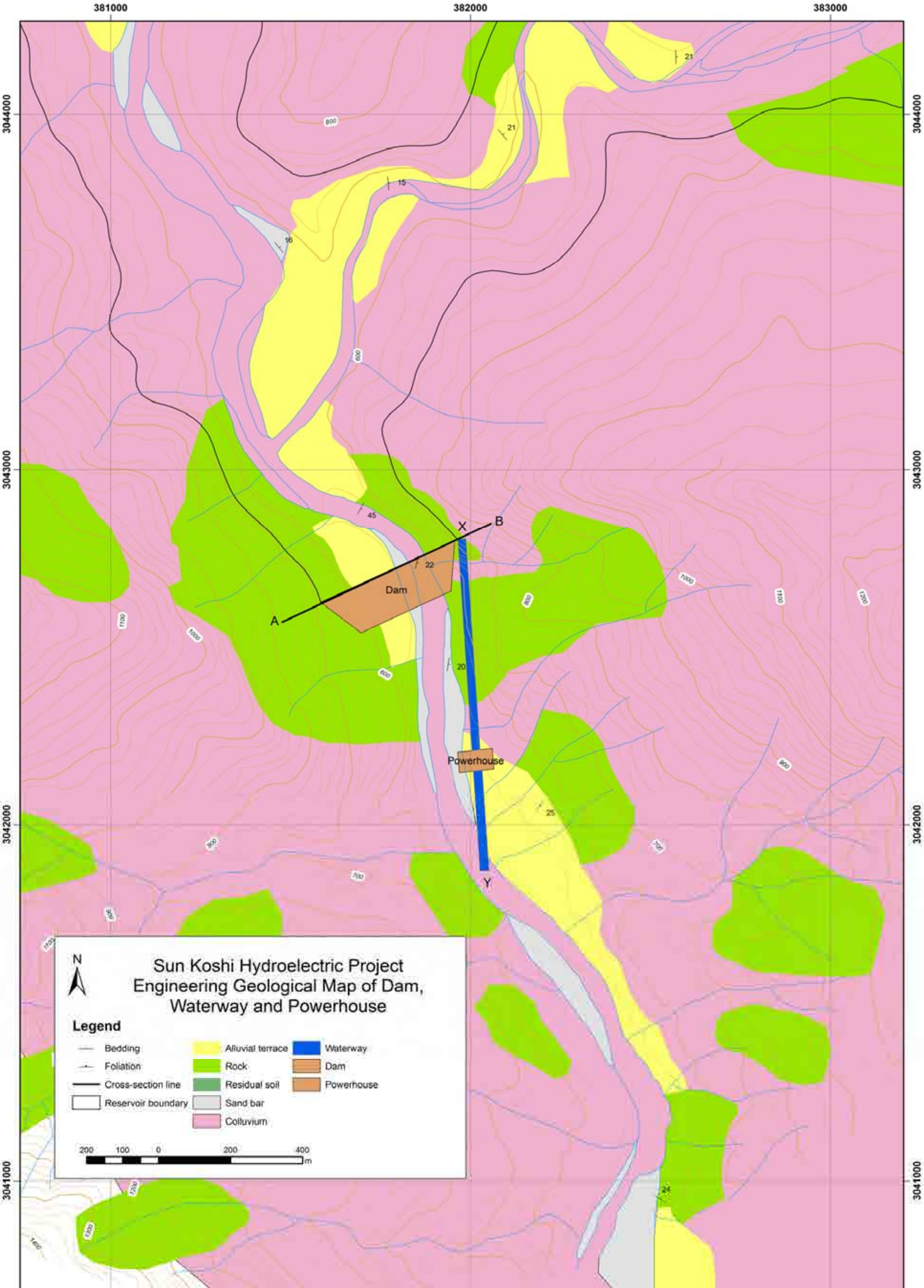

Figure 1.5: Engineering geological map of the dam axis, waterway and powerhouse area.

Figure 1.6: Dam site of the Sunkoshi HEP, at location 128.

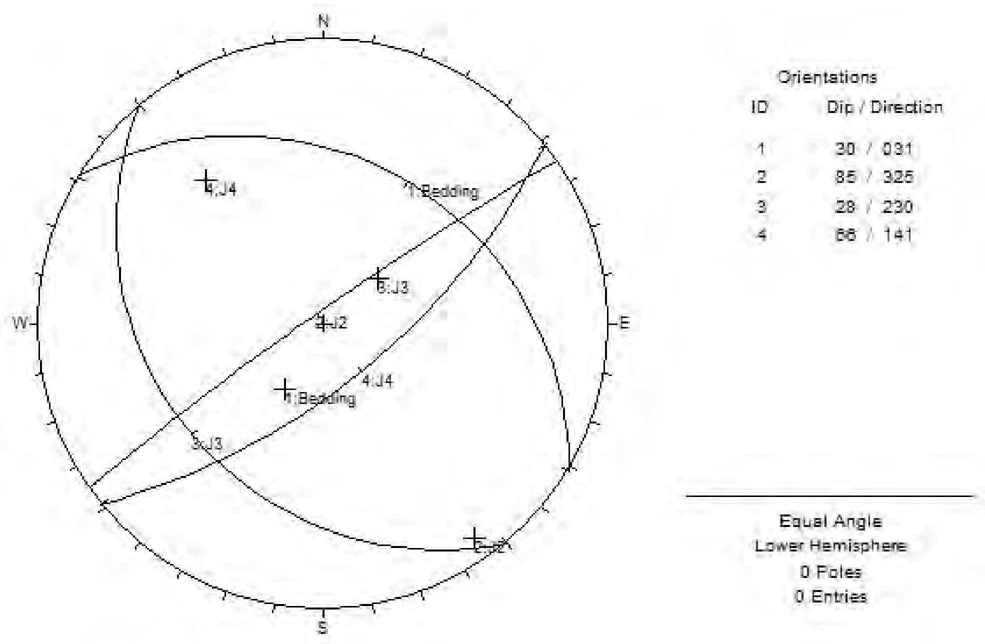

Figure 1.7: Stereoplot of the major discontinuities at the dam site of the project area (at location 128).

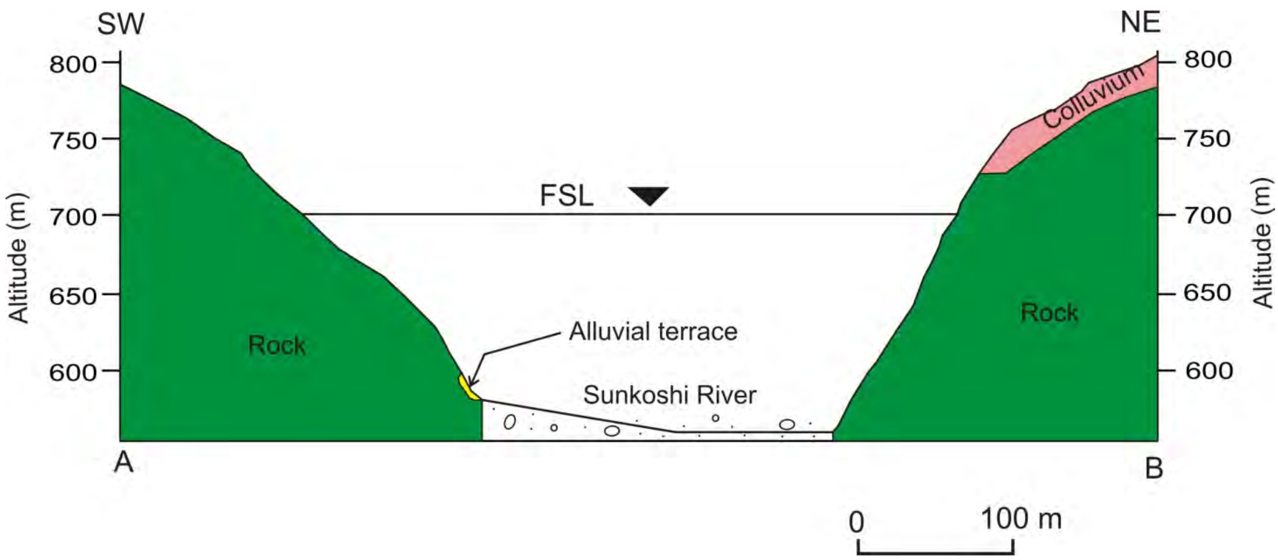

Figure 1.8: Cross-section along the dam

1.4 Waterway

The waterway which is about 700 m long passes along the left bank of the Sunkoshi River (Figure 1.5). It encounters rocks of the Kuncha Formation. Along the waterways dominantly medium-to thick-bedded medium grained to gritty quartzites with partings and thin bands of gritty phyllite are common. Three major disconitinuity sets were observed along the waterway.

The overburden along the proposed headrace tunnel is less than 50 m. Owing to the dip of foliation and bedding some precautions are required during construction to overcome roof collapse. The cross-section along the waterway is given in figure 1.9.

1.5 Powerhouse

The Powerhouse is located at the terrace on the left bank of the Sunkoshi River. In the powerhouse site, there is a wide cultivated alluvial terrace (Figure 1.10) on which village is situated. Above the terrace there are some rock outcrops with colluviums. Rock consists of alternating bands of medium-to coarse-grained grey quartzite with few bands and partings of greenish grey phyllite. The stability condition of the powerhouse is ok but there may encounter some problem during the construction of Penstock as above the terrace there is some colluvium. So during the construction of penstock detailed study of the area is essential.

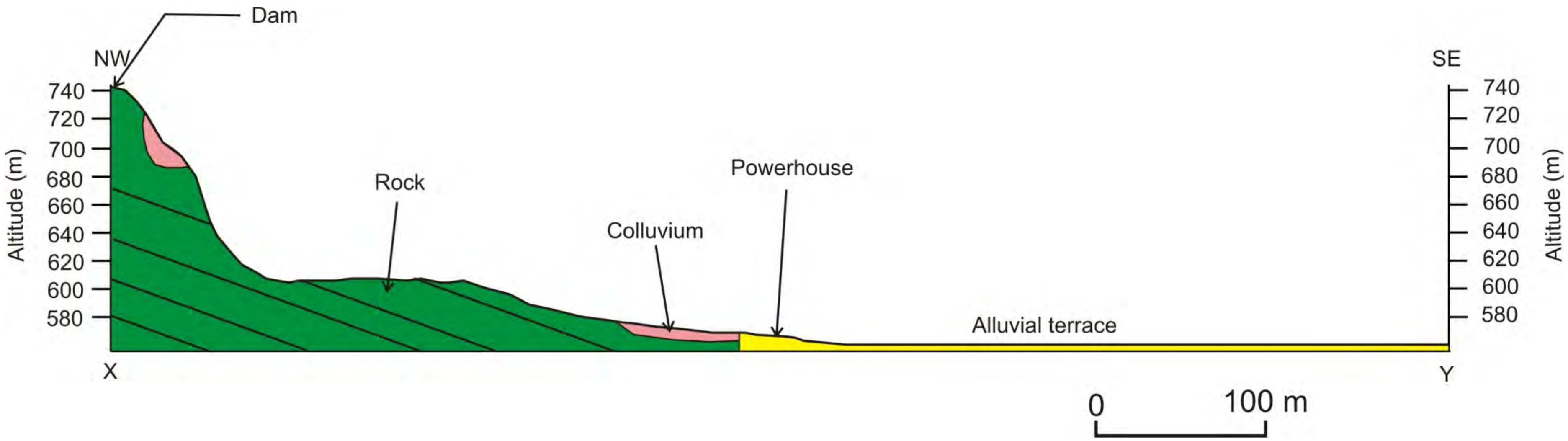

Figure 1.9: Cross-section along the waterway

Figure 1.10: Powerhouse site of the Sunkoshi HEP, at location 126.

1.6 Instabilities

A major fault with a thick shear zone passes along the left bank of the Indrawati River along the road from Bodgaun to Bisdevtar. No major landslides were observed on the project area except some small soil and rock slide due to man-made causes especially due to road construction. One of minor slide is shown in figure 1.11.

Figure 1.11: Landslide along the Sunkoshi River between Jagate and Timreni Bensi, at location 153.

1.7 Construction material

For the construction materials, the required quantity of sand is available in the Sunkoshi River about 9 km downstream from the proposed dam site around the confluence of the Sunkoshi and the Rosi Khola. As most part of the study area comprises quartzite, the required quantity of aggregate can be obtained from the quarry as well as from the riverbed itself. The required aggregate can also be obtained by crushing the siliceous limestone found in the Jhiku Carboante band of the Benighat Slate. Large outcrops of these rocks are observed along the Jhiku Khola.

1.8 Recommendation

Detailed study of the hill slope at the powerhouse is essential. Powerhouse and tailrace canal lies in the alluvial terrace so it is recommended to conduct geophysical investigation in this site.

Table 1.1: GPS locations in the project area and photograph number

TYPE	IDENT	LAT	LONG	ALTITUDE	Photo number
WAYPOINT	274	27.73813600	85.61284500	717.64	6084-6085
WAYPOINT	275	27.73285100	85.61815600	702.90	6086-6088
WAYPOINT	276	27.72908100	85.62620900	689.08	DSCF0779-783
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WAYPOINT	242	27.65046000	85.70128400	752.15	5970-5976
WAYPOINT	243	27.65359700	85.69698400	759.26	5977-5982
WAYPOINT	244	27.65808800	85.69370700	769.79	5983-5986
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WAYPOINT	125	27.48883800	85.80651100	570.77	DSCF0190-193
WAYPOINT	126	27.49136500	85.80532500	554.33	DSCF0194 and 195
WAYPOINT	127	27.49495200	85.80272500	555.94	DSCF0196-199
WAYPOINT	128	27.49753600	85.80180900	573.67	DSCF0200-203
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WAYPOINT	140	27.52689500	85.81855500	655.36	DSCF0272-276
WAYPOINT	141	27.52911100	85.81842000	659.38	DSCF0278-285
WAYPOINT	118	27.51148300	85.80670400	612.44	5757-5761
WAYPOINT	119	27.51164900	85.80520700	602.28	5762-5765

Table 1.2: Attitude of bedding (B) and foliation (F) planes measured at different locations

Waypoint	Strike	Dip Amount	Dip Direction	Type
119	60	16	N	B
120	100	35	N	B
123	121	24	N	B
126	30	25	S	B
127	9	20	S	B
128	11	22	S	B
129	210	45	S	B
132	355	15	N	B
133	141	21	N	B
135	178	21	N	B
136	337	16	N	B
138	266	26	N	B
142	321	16	N	B
145	76	20	N	B
146	156	24	N	B
149	76	14	N	B
153	109	16	N	F
155	126	28	N	F
156	94	21	N	F
158	114	26	N	B
160	129	18	N	B
163	256	74	N	F
165	286	56	N	F
167	274	76	N	B
169	113	49	N	B
170	71	71	N	B
172	114	74	N	B
173	153	60	N	B
174	76	64	N	F
183	210	52	N	B
184	216	45	N	B
186	90	24	N	B
187	171	33	S	B
188	172	37	S	B
190	184	49	S	B
191	342	45	S	F
196	12	68	N	B
200	37	21	S	B
204	112	50	S	F
207	113	46	S	B
208	133	46	S	B
209	46	83	S	B
210	97	46	S	B
211	110	30	S	B
213	223	52	S	B
215	88	50	S	B
216	246	65	S	B
218	66	68	S	B
219	64	54	S	B

Waypoint	Strike	Dip Amount	Dip Direction	Type
221	170	44	N	B
222	114	28	S	B
223	160	43	S	B
224	140	27	S	B
225	161	51	S	B
226	172	47	S	B
229	76	23	S	B
231	88	60	S	B
232	96	57	S	B
233	121	74	S	B
234	96	56	S	B
236	16	22	S	B
238	165	25	S	B
243	172	68	S	B
245	152	35	S	B
246	153	36	S	B
251	152	33	S	B
254	113	79	S	B
258	78	61	S	B
261	151	41	S	B
263	71	31	S	B
264	152	65	S	B
266	109	57	S	B
272	96	27	S	B

Table 1.3: Geological Study Team Members and Itinerary of the Field Visits

Name of Project	District	Date of field visit	Name of the Geologlist	Investigation method
Sunkoshi	Kavrepalanchowk and Sindhuli	8th July – 14th July, 2012	Dr. Kamala K. Acharya Mr. Baburam Gyewali Mr. Laxman Subedi	Geological reconnaissance survey

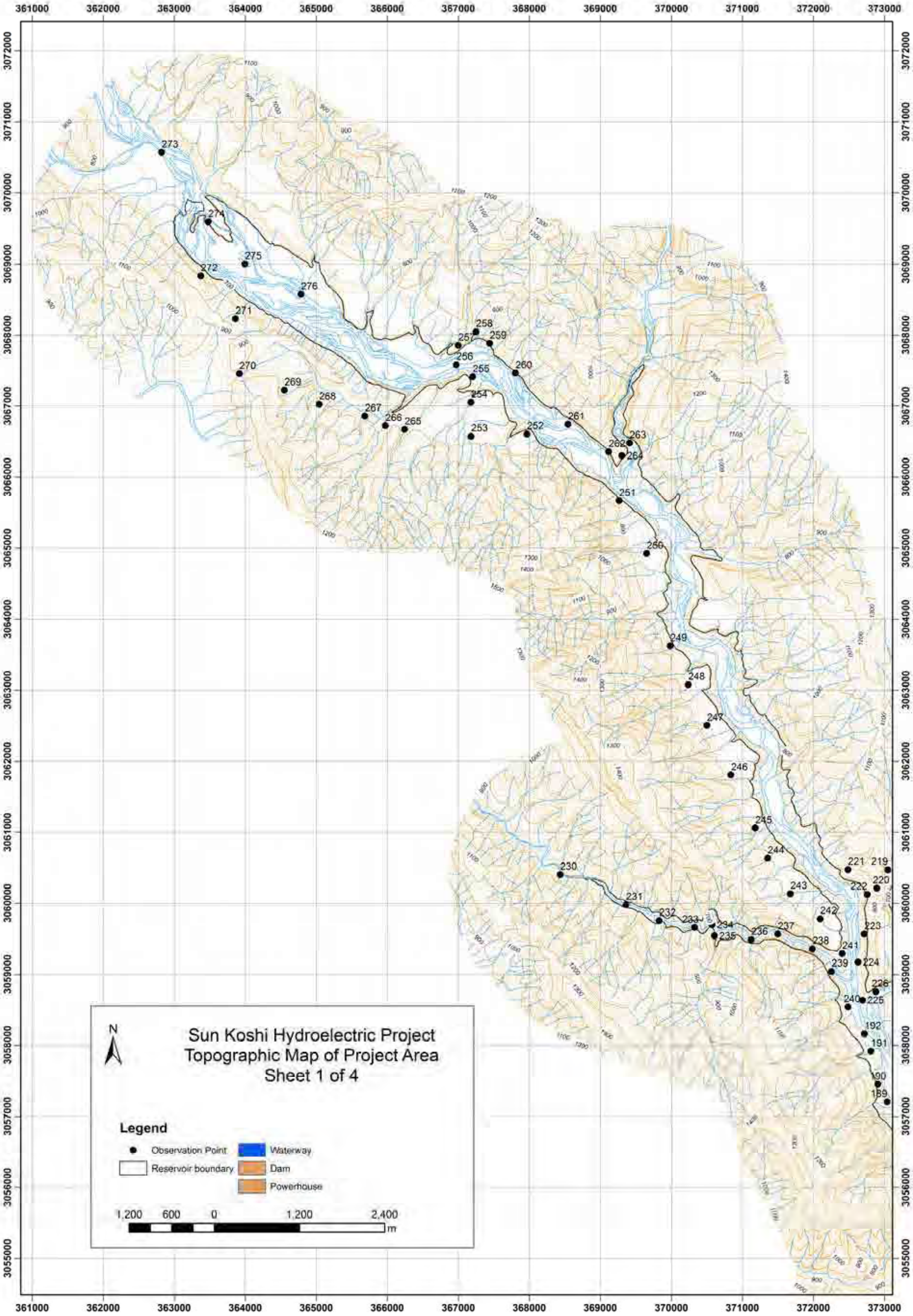

Figure 1.12: Topographic map of the Sunkoshi HEP showing observation point

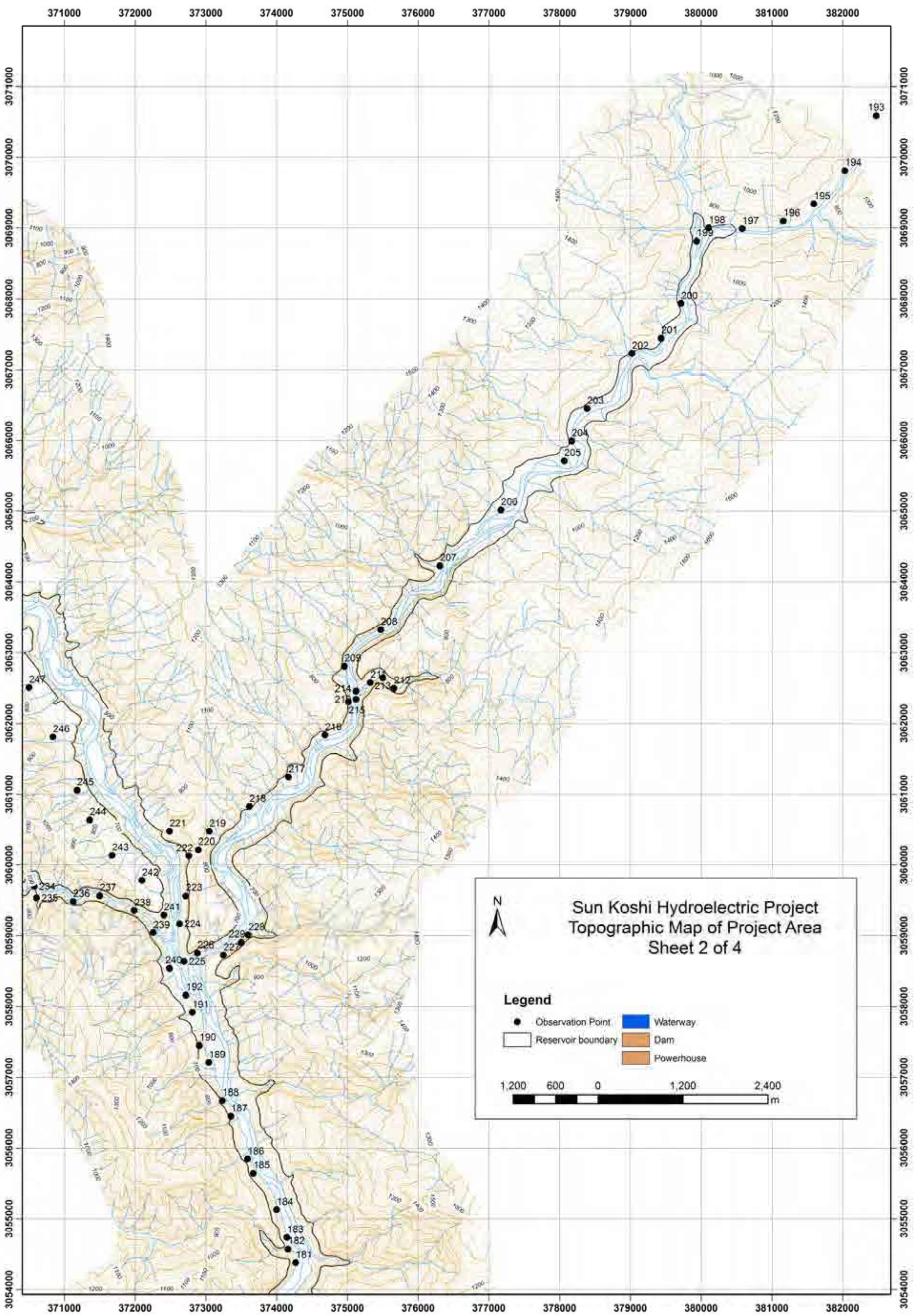

Figure 1.12: Topographic map of the Sunkoshi HEP showing observation point (contd.)

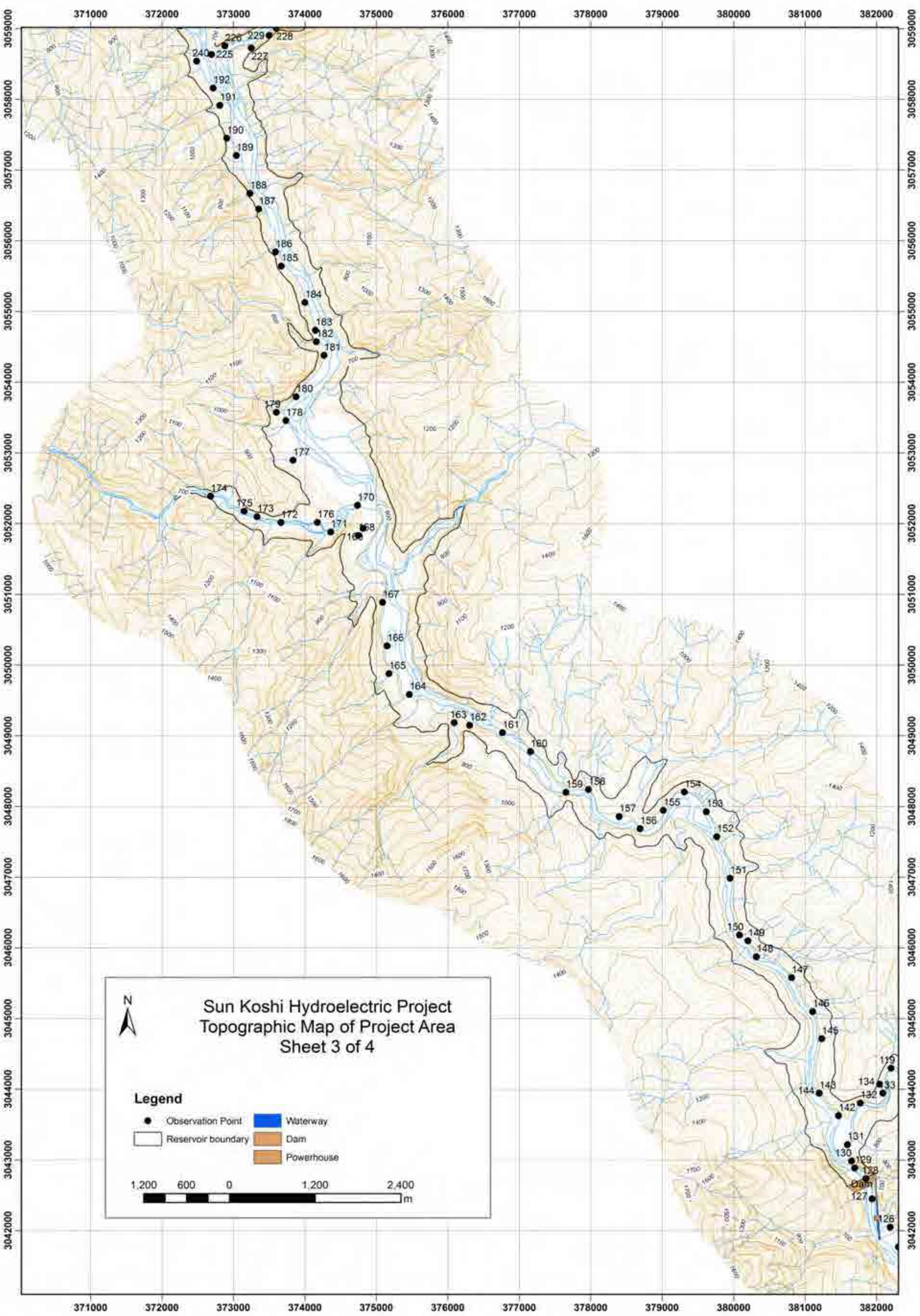

Figure 1.12: Topographic map of the Sunkoshi HEP showing observation point (contd.)

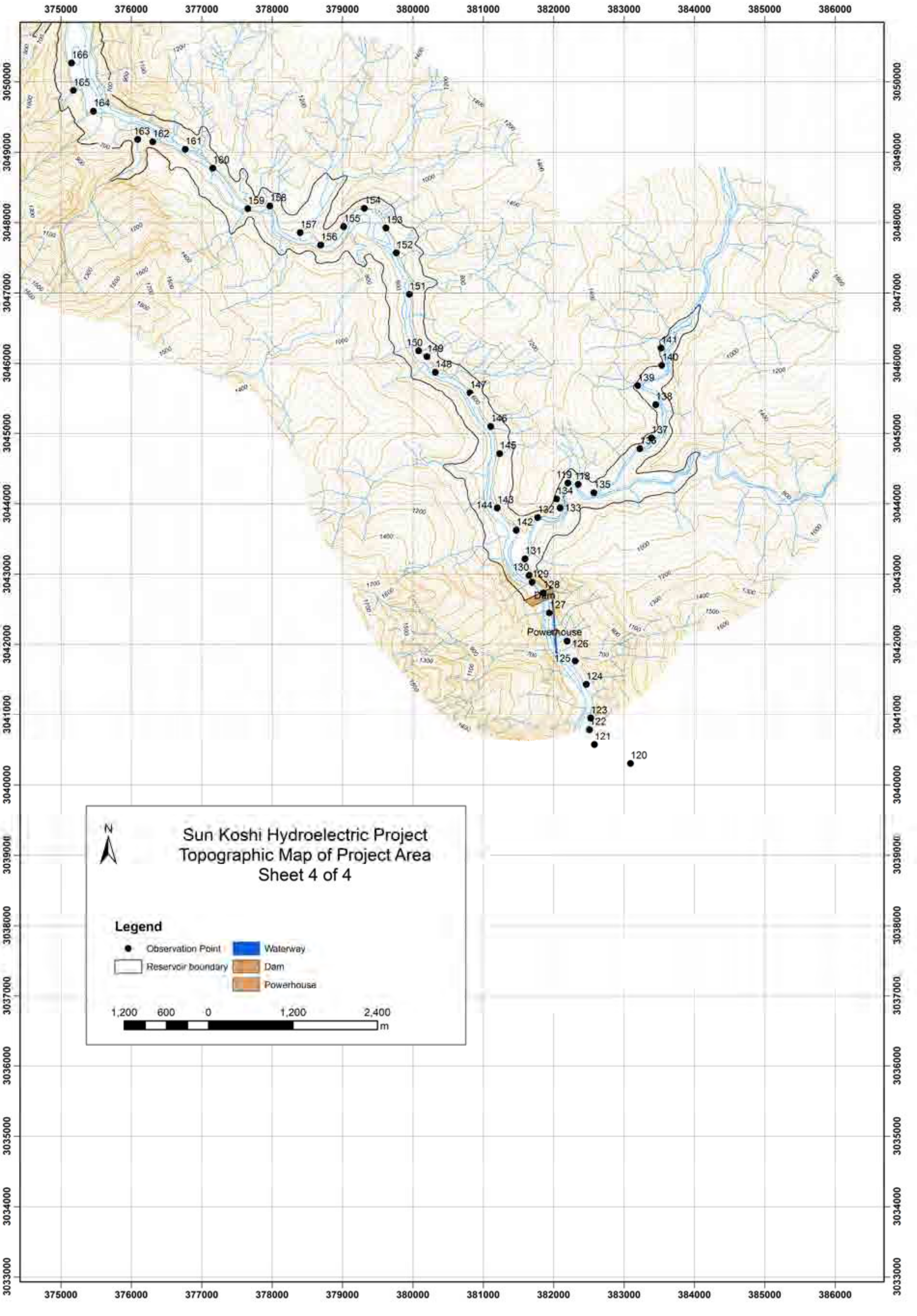

Figure 1.12: Topographic map of the Sunkoshi HEP showing observation point (contd.)

Annex 4: Geological Survey Report

Lower Badigad Project (C-02)

Table of Contents

Introduction

This Report deals with the engineering geological investigations in the Lower Badigad hydroelectric dam projects. This project area was surveyed by Dr. Sunil Kumar Dwivedi, Mr. Lalit Rai, and Mr. Gautam Khanal between 9 and 15 July 2012. Geology and engineering geology of this project are summarized below.

1 Lower Badigad Project

The Lower Badigad HEP is located about 500 km west of Kathmandu in the Gulmi district of western Nepal. The project uses water from Badigad River that flows northwest to southeast. The Dam site is located at about 5 km upstream of the confluence of BadigadKholaand Kaligandaki River, while Powerhouse site is located on the right bank of BadigadKhola at Rudrabeni which is about 400 m west to the confluence of Badigad and Kaligandaki River. The reservoir and headworks area of the project can be accessed by Ridi-Burtibangmotorable gravel road.

1.1 Geology of project area

Geologically, the project area lies in the Lesser Himalayan Zone composed of meta-sedimentary rocks such as shale, slate, limestone, dolomite and quartzite. The geological map by the Fuchs and Frank (1967) shows Precambrian Lesser Himalayan rocks (Figure 1.1) represented by Riri Slates, Krol or ShaliLimestones and Simla Slates in the project area.

The Lesser Himalayan Zone is characterized by the rugged and dissected topography. The Badigad Fault, which is an active fault, passes through the Badigad River in the project area. The rocks of the area are intensely fractured and folded. Deformed quartz veins and ptygmatic folds are common in upper reaches of the reservoir area.

Lithology: The lesser Himalayan rocks constituting the Lower Badigadreservoir and dam siteis represented by Slate intercalated with Limestone beds in the upper part,where dark grey slates are intercalated with thin grey calcareous slates, and Purple Quartzite and Shale beds in the lower part, where the pinkish or purplish calcareous quartzites and quartziticlimestonesare intercalated with dark grey purple and green shales(Figure 1.2).The underlying rocks over Slate intercalated with Limestone are Limestone and Dolomite which consists of light blue, grey limestones and dolomites with thin interactions of grey shales, white, pink dolomite limestones, purple quartizes and green shales. The Limestone and Dolomite are underlain by Black Slate which is represented by black, dark grey to greenish grey shales and slates with interaction of limestones and quartzites

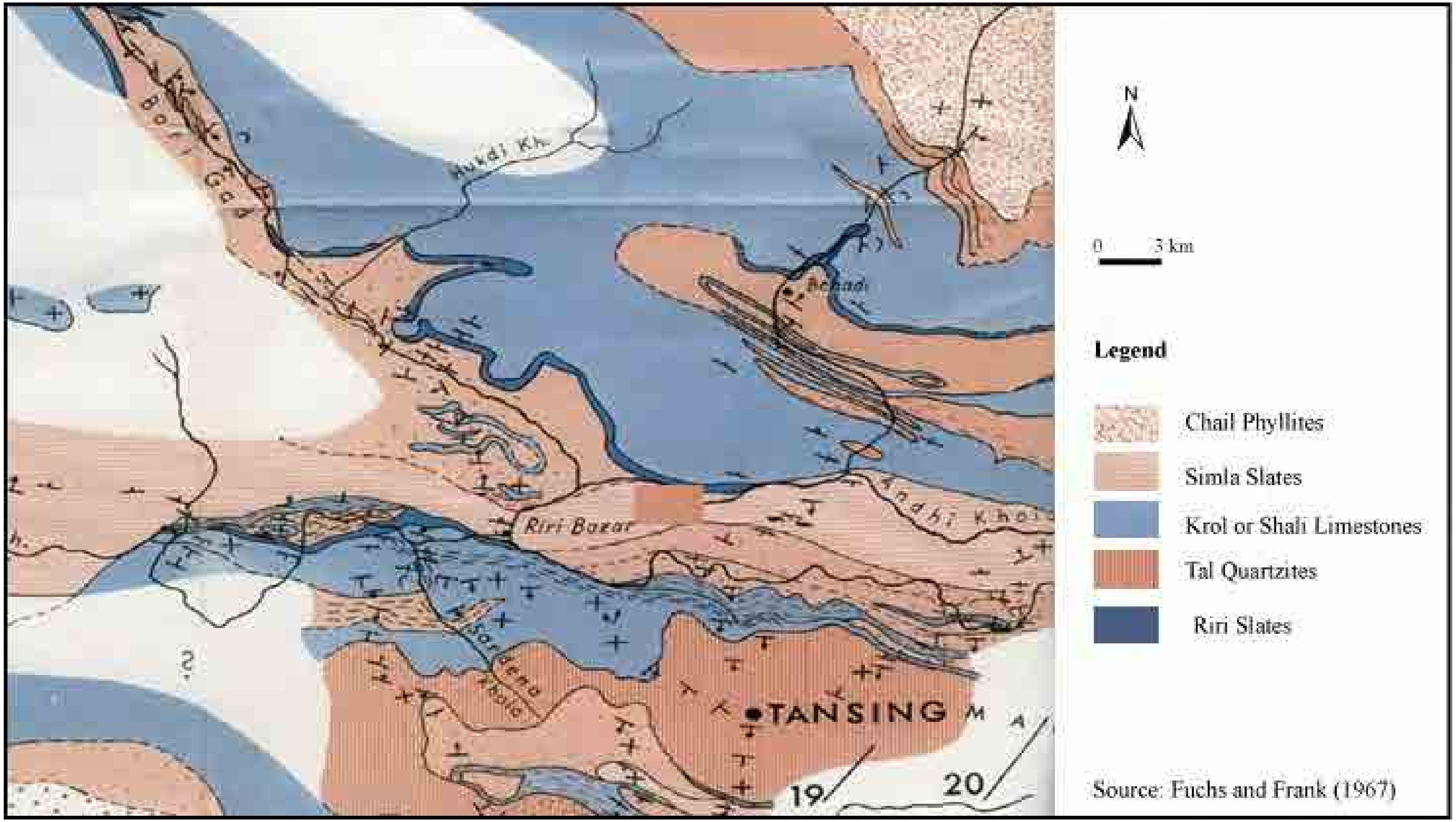

Figure 1.1: Regional geological map of the project and its surrounding area, after Fuchs and Frank (1967)

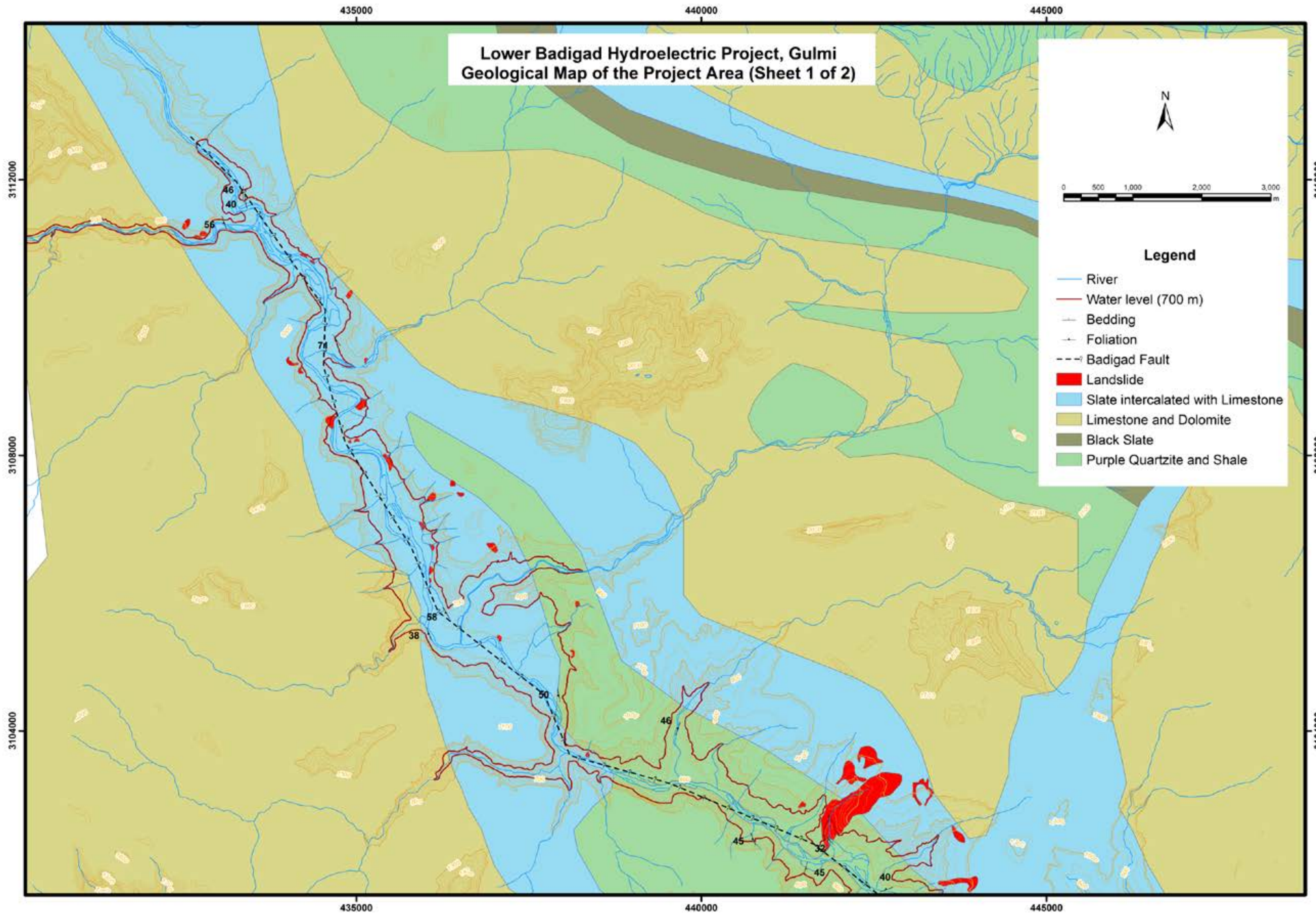

Figure 1.2: Geological map of the project with reservoir, dam site, intake and powerhouse area

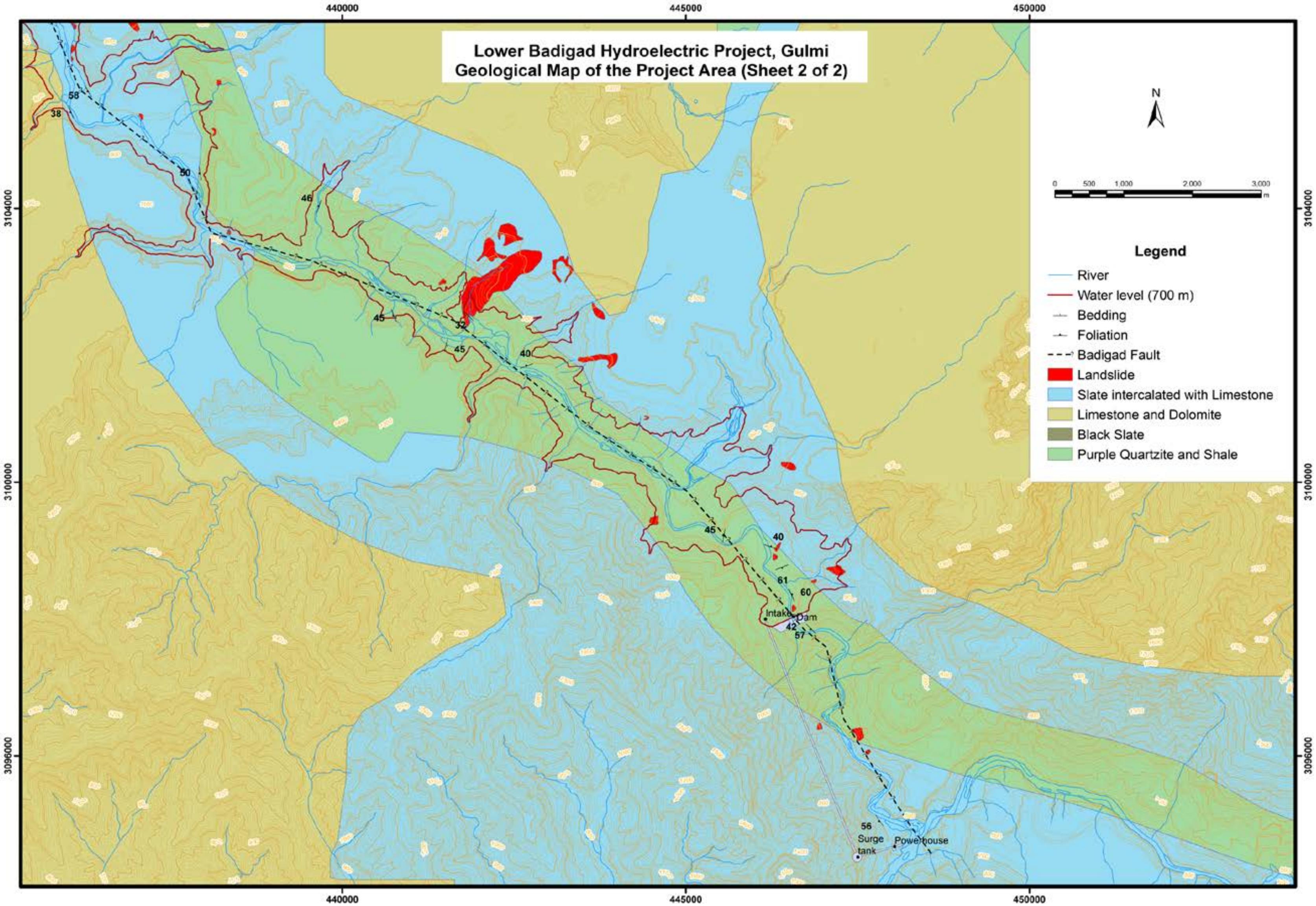

Figure 1.2(continued.): Geological map of the project with reservoir, dam site, intake and powerhouse area

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Faluts: Except the Badigad Fault which passes throughout the project area, no other fault exist in the dam site, water way and powerhouse area.

Quaternary deposits: Alluvium, colluvium, residual soil, debris flow deposits (alluvial fans) and sand bar deposits are distributed on the valley of the BadigadKhola and its main tributaries (Figure 1.3). The alluvial deposits are well distributed in the lower valley slopes in TallaphantGaun, Rampu, ThulaPhat, AnpchaurGaun, Sotaphat, Ullikhola, ArungaBajar, Juhan and Khaireniand are less than 40 m thick.

The colluvium is dominantly found on moderately steep to gentle slopes and spurs while residual soil is limited in the upper slopes of the reservoir area.

Residual soil is common in Amlabot, GhyasiKharka, Mimnekothum, Kumal, DangsingDamar, Turang, Ambot, DeraliGaun, BataseGaun, KhaireniGhat, Saudi, Jubhung, ButilGaun, Nakethum, Ghultungaun, Chega, Bamgha, Botegaun, Pipaldada and Dwaga.

It can be seen clearly that the river valley of BadigadKhola is widened in most part of the reservoir area where alluvial deposits are widely distributed. This points out to active left lateral movement along the Badigad Fault from the past to the present.

Rock mass condition: The metasedimenary rocks of the project area are comparatively moderate to strong. The overall stability of the rock mass is fair to good. The resistant quartzite, limestone and dolomite form steep cliffs, gorges, and sharp peaks, whereas the shales and slate forms a smooth spur and ridge or gentle valley with good vegetation. The slate intercalated with limestone of the reservoir are stronger, and they are followed by the stronger purple quartzite and weaker shale downstream.The weakest unit is the dark grey purple and green shales of dam site which are followed by moderately stronger dark grey slates intercalated with calcareous slates and limestone of the powerhouse area.

Weathering: Water, air and sun has played a significant role in weathering of rock in the project area. The weathering depth in rocks of project area reaches up to 5 m and sometimes more.

Weathering of resistant quartzite beds, limestone, dolomite and shale has resulted into the widespread distribution of colluvium, talus cones and debris flow fans. Weathering of the Purple Quartzite and Shalehas developed colluvial soils on the middle slopes, especially around the village of Sajbot, Chorkateghat, Dhawagaun, Gultung, Ritaudigaun, Botegaun, Kuduletapu, Dhandgairagaun. The weathered Slate intercalated with Limestone of reservoir yield finer colluvial soil near GhyasiKharka, BhukwaPhat, Char Khutte and Kumal, and sporadically residual soil on ridges near Ramthum, Mimnekothum and DangsingDamar. The effect of weathering on quartzites is seen in widening of joints, their slight discoloration, or infilling by silt and clay. But the rock generally remains strong. On the other hand, the shales strongly change their colour (become yellow, pink, yellow, green and brown), get a smoother surface, and the rock around joints and bed loses its strength. On the other hand, limestone and dolomite either are transformed into dissolution cavities or their colour has yellow or brown tints.

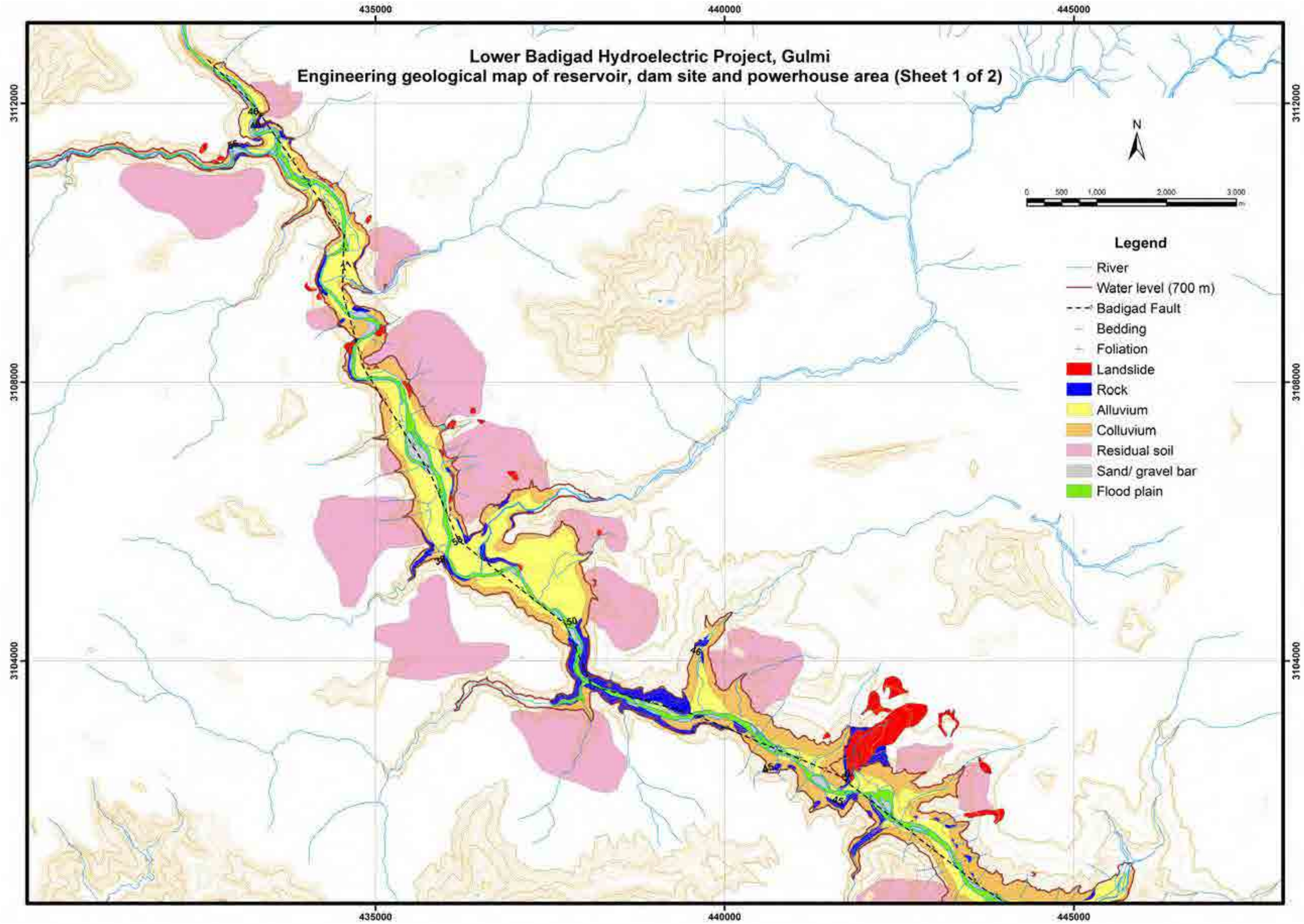

Figure 1.3: Engineering geological map of reservoir and its surrounding area.

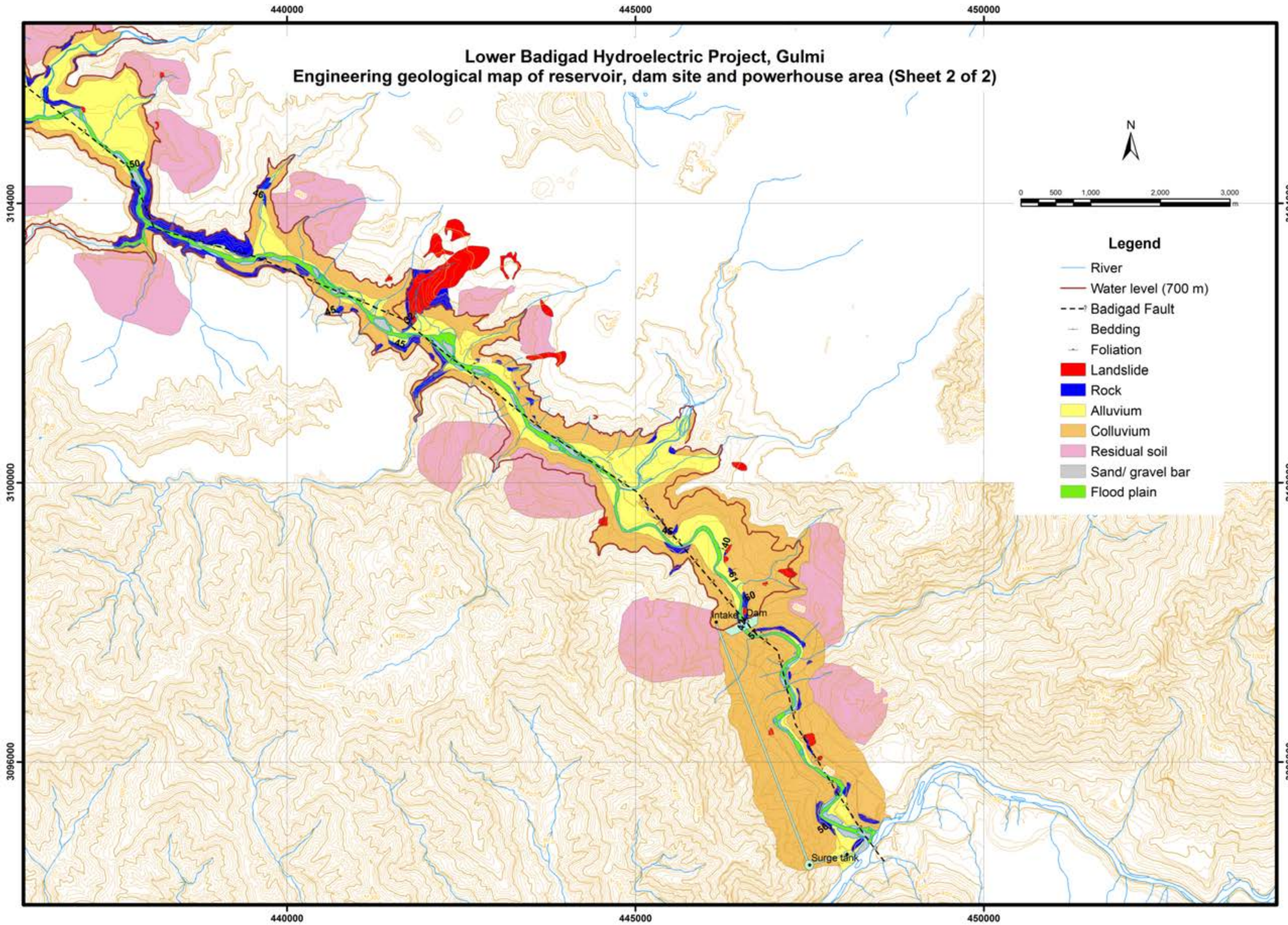

Figure 1.3 (continued.): Engineering geological map of reservoir and its surrounding area.

Jointing: Three discontinuity sets are clearly seen in the Lower Badigadproject area (Table.1.2) the three sets are almost perpendicular to each other, especially in quartzites, limestone and shales. The shale contains rough and wavy joints that do not continue for more than 4 or 5 m. On the other hand, the limestone and dolomite contains very irregular joints. The joints are straight to slightly wavy in the quartzites and limestones, where their aperture ranges from less than 1 mm to 5 mm, but some joints are rather wide (up to 1 cm) and continue for few metres.

Stability conditions: The rock soil slopes in the project area are generally stable. Some past instabilities, which are difficult to delineate at present, were noticed in the right bank of dam site. The main source of sediments in the BadigadKhola is the debris flow from ChhaldiKhola, KhabangKhola, GediKhola, TekwaKhola, HugdiKhola, JumliKhola, SodiKhola, TardiKholaand its tributaries. Landslides are observed mostly on colluvial slopes and joint controlled steep rock slopes such asseen near the village of Kumal, Turang, Juniya, Juhan, and Imgha (Figure 1.3). Mainly wedge slides, plane rockslides and debris slides,are found in the project area.The water of BadigadKhola is clean and clear during the dry period. However, during the time of monsoon season the frequent debris flows from its tributary streams causes the water excessively turbid. Therefore, some measures are required to deal with this problem.

Groundwater conditions: The BadigadKhola, its tributaries ChhaldiKhola, GediKhola, HugdiKhola, BharseKhola, JumliKhola and LumdiKholaare perennial whereas some minor gullies are seasonal. Limestone and dolomite of reservoir area are relatively pervious, while quartzites and shale of reservoir and dam site are quite impervious, which is favourable permeability condition for dam construction.

1.2 Dam axis

The proposed dam axis is located in the narrow gorge of Badigad river valley where quartzite and black shale bedsare observed on both flanks (Figures 1.6 and 1.7). Qurartzites are purple and occasionally calcareous while shales are dark grey, purple and green in color. The rocks are blocky, locally fractured, jointed, and moderately weathered. The rock is medium strong to strong with expected uniaxial compressive strength in the range of 50 - 100 MPa. Therefore, the rock is categorised as good.

The dam axis is found appropriate owing to the stability of both banks. The distribution of foliation and joints around the dam axis is presented in Figure 1.4, where the steeply dipping prominent bedding and rather random but gently to steeply dipping joints are evident.The dipping of foliation is SW with dip amount ranging from 35 – 45 degree. The other two prominent joints dips towards SW and NE at 55 - 70 degrees to almost vertical. The strike of the rock is almost perpendicular to river with bed dipping towards south. This orientation of rock is favourable for the construction of high dam. Uphill side of left and right bank of the Dam site is steep sloped (>50^{o}). No major geological hazards are expected in the dam site area.

The foundation and the area around the dam axis are impervious which also shows favourable condition for dam construction. It is proposed to construct a rock-fill dam, since there is a narrow gorge, and the boulders of quartzites are easily available along the valley of BadigadKhola near dam site.

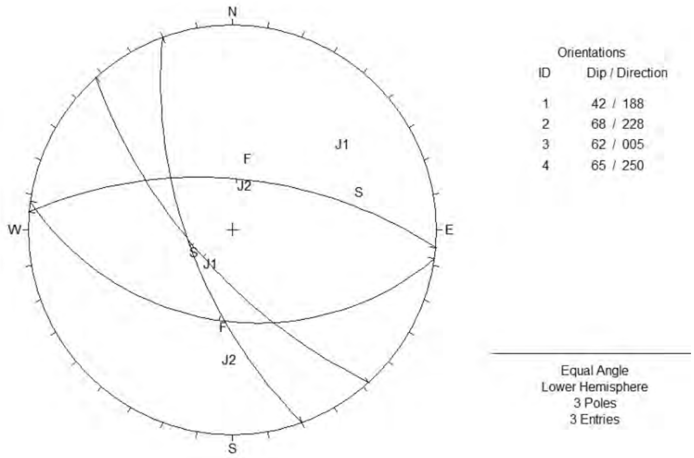

Figure 1.4: Stereographic projection of the foliation (F), major discontinuity planes (J1 and J2) and hill slope (S) at the left bank of the dam site.

1.3 Reservoir

BadigadKhola and its main tributaries ChhaldiKhola, GediKhola, HugdiKhola, BharseKhola, JumliKhola and LumdiKhola cover the proposed reservoir area. The water level (700 m) in the reservoir extends up to RayalePhat in the northwestern part and upto Pipaldanda in the southeastern part of the project area.The villages that will be underwater are TallaphantGaun, Rampu, ThulaPhat, AnpchaurGaun, Sotaphat, Ullikhola, ArungaBajar, Juhanand Khaireni, and also completely submerges the existing Ridi-Burtibang road. The area to be under water consists of bedrock, alluviamand colluvium with some minor instabilities.Since the reservoir area mostly consists of moderately permeable rocks like dolomite and shales, the area is moderately water tight. The engineering geological map of the reservoir and its surrounding areas is presented in Figure 1.3.

The stability in the surrounding areas of the reservoir is relatively sound. The present study reveals no significant weak or vulnerable zones leading to dam collapse or large failures obstructing the reservoir exceptGultungPahiro, a large active landslide which lies in the centre of the reservoir area andbrings huge amount of debris to the BadigadKhola. Protective measures such as check dams are therefore needed to construct to prevent the high sediment inflow into the reservoir from GultungPahiro as well as other small landslides and debris flow deposits upstream of the reservoir.

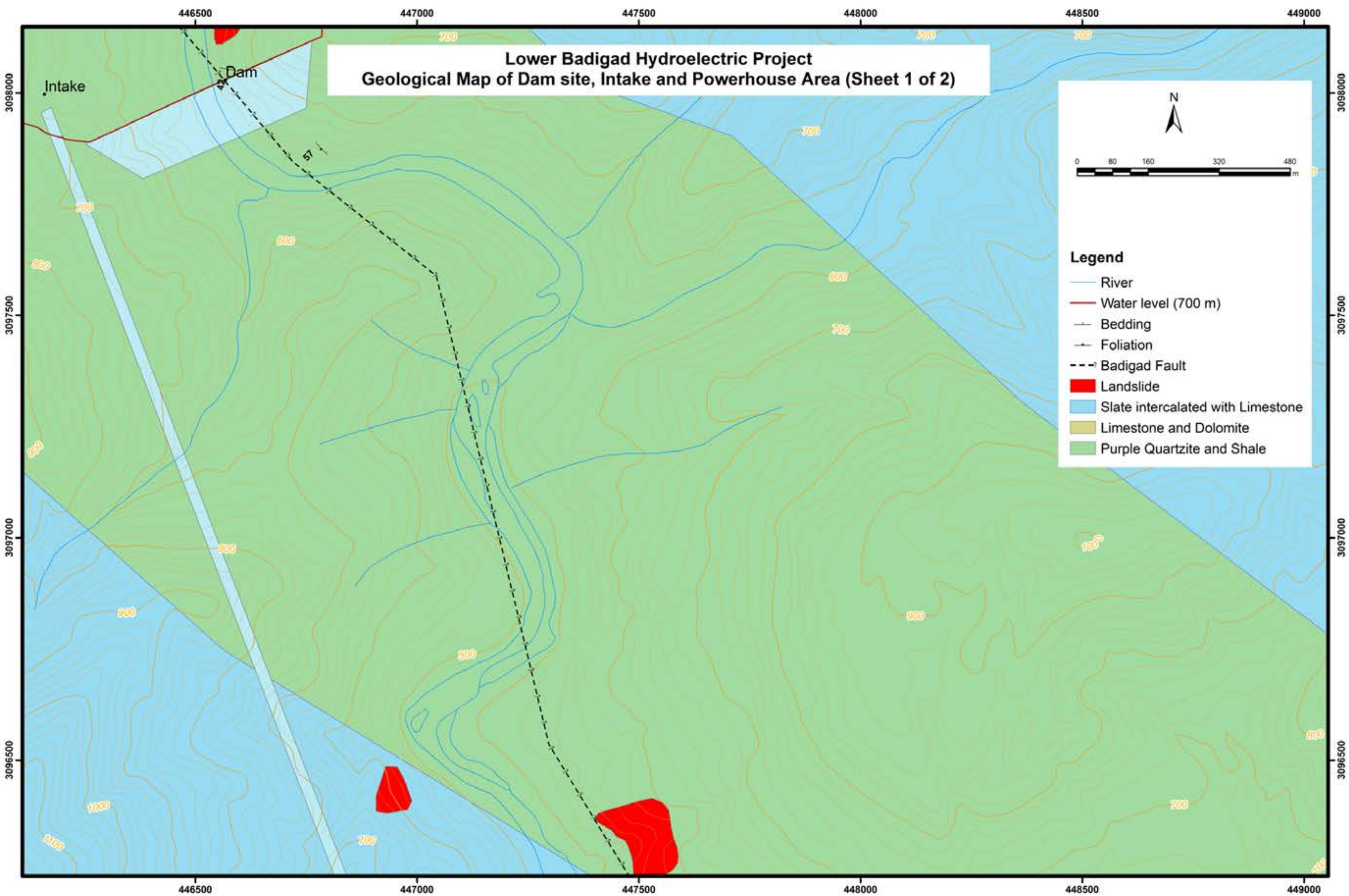

Figure 1.5: Geological map of dam site, intake, water route and powerhouse area.

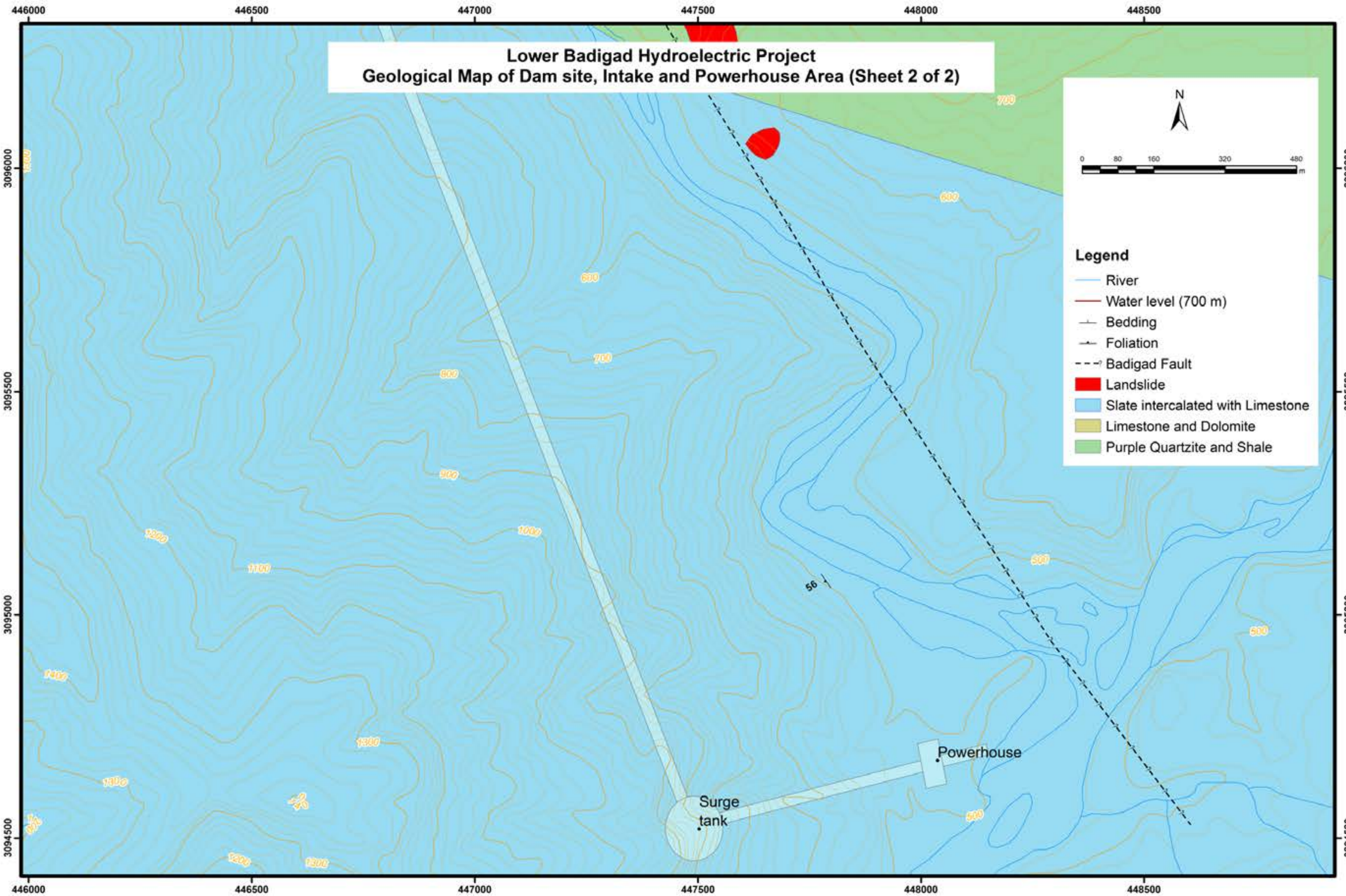

Figure 1.5（continued）: Geological map of dam site, intake, water route and use area.

1.4 Waterway

An intake tunnel (Figure 1.6) is proposed on the right bank of the BadigadKhola, near the west end of the dam. The area is made up of steep quartzite and shale beds with colluvial deposits along the slope.

The proposed headrace tunnel passes through Slate intercalated with Limestone beds in the lower part, where dark grey slates are intercalated with thin grey calcareous slates, and Purple Quartzite and Shale beds in the upper part near powerhouse, where the pinkish or purplish calcareous quartzites and quartziticlimestones are intercalated with dark grey purple and green shales (Figure 1.8). The overburden along the proposed headrace tunnel varies from less than 80 to 200 m. Generally the headrace tunnel alignment makes an acute angle with the foliation plane. In this area, the foliation is moderately dipping due south to southwest.The moderatedip of beds is favourable in terms of stability for tunnel construction.

1.5 Powerhouse

Powerhouse site is located on the right bank of BadigadKholaon the alluvial terrace at Rudrabeni which is about 400 m west to the confluence of BadigadKhola and Kaligandaki River (Figures 1.6 and 1.14).The alluvial terrace is about 300 m wide, 400 m long and about 30 m depth.Below the powerhouse site, there is about 300 m long (from the east to west) and about 100 m wide sand and gravel bar of the BadigadKhola. The bedrock that can be expected at the powerhouse site is at the depth of more than 40 m. The bedrock, joints and valley slope behind powerhouse shows stable slope conditions. However, there is some possibility of channel shifting and scouring of the alluvial terrace by both BadigadKhola and Kaligandaki River during high flooding events.Hence protective measures should be adopted during construction of powerhouse foundation.

1.6 Instabilities

Some important landslides are shown in Figures 1.3 whereas a large alluvial fan to be submerged in the reservoir area is depicted in submitted photographs.

Mostly landslides are common on quartzites, shale and limestones and colluvial terraces of the reservoir (Figures 1.3, 1.6 and 1.15). Mainly rockslides (wedge and plane failures) are observed on shales and quartzites. The landslide and other instability distribution in the reservoir and its vicinity were assessed from field observations and satellite image interpretations. GultungPahirois a large active landslide that poses threat to the local people as it brings huge amount of debris to the Badigad River (Figure 1.11).

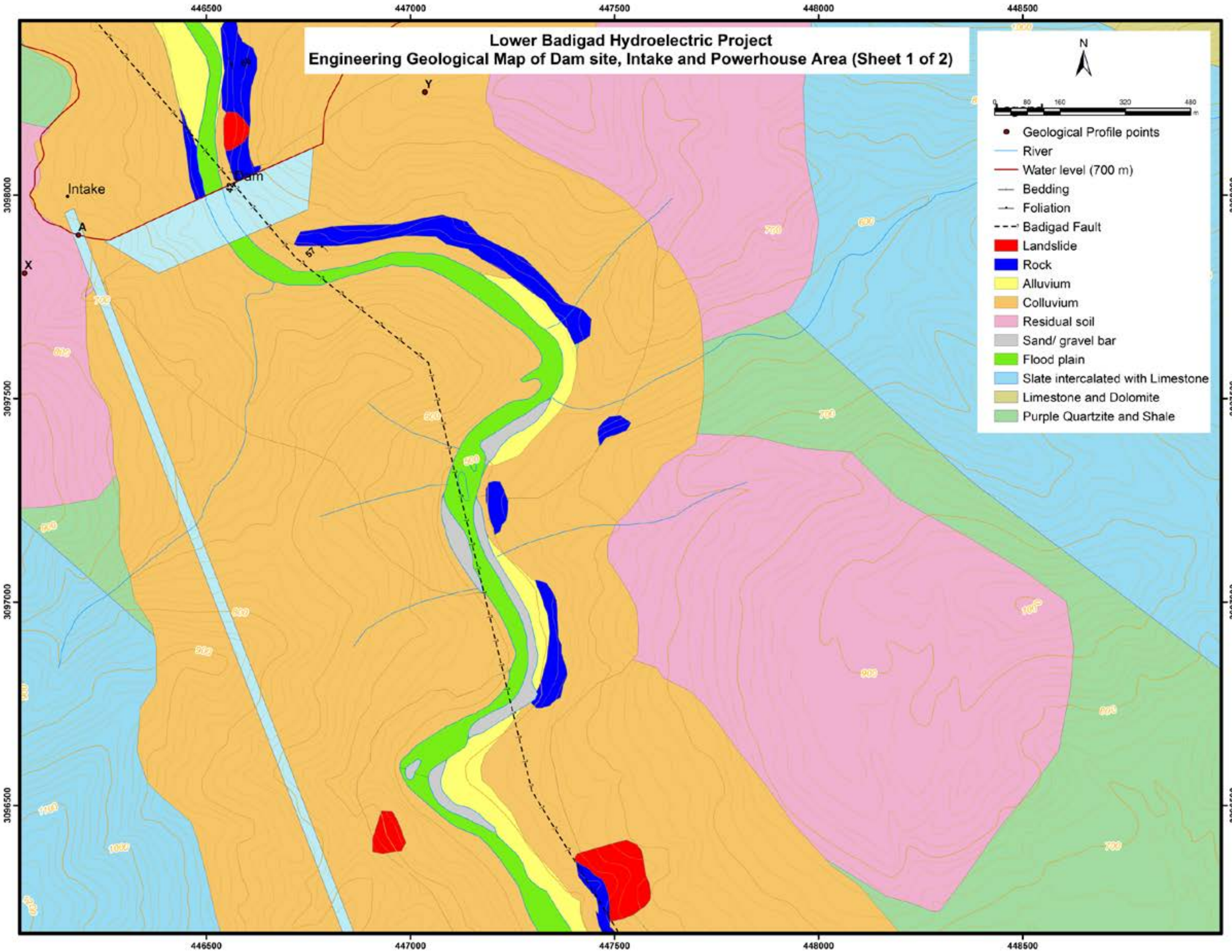

Figure 1.6: Engineering geological map of dam site, intake, water route and powerhouse area.

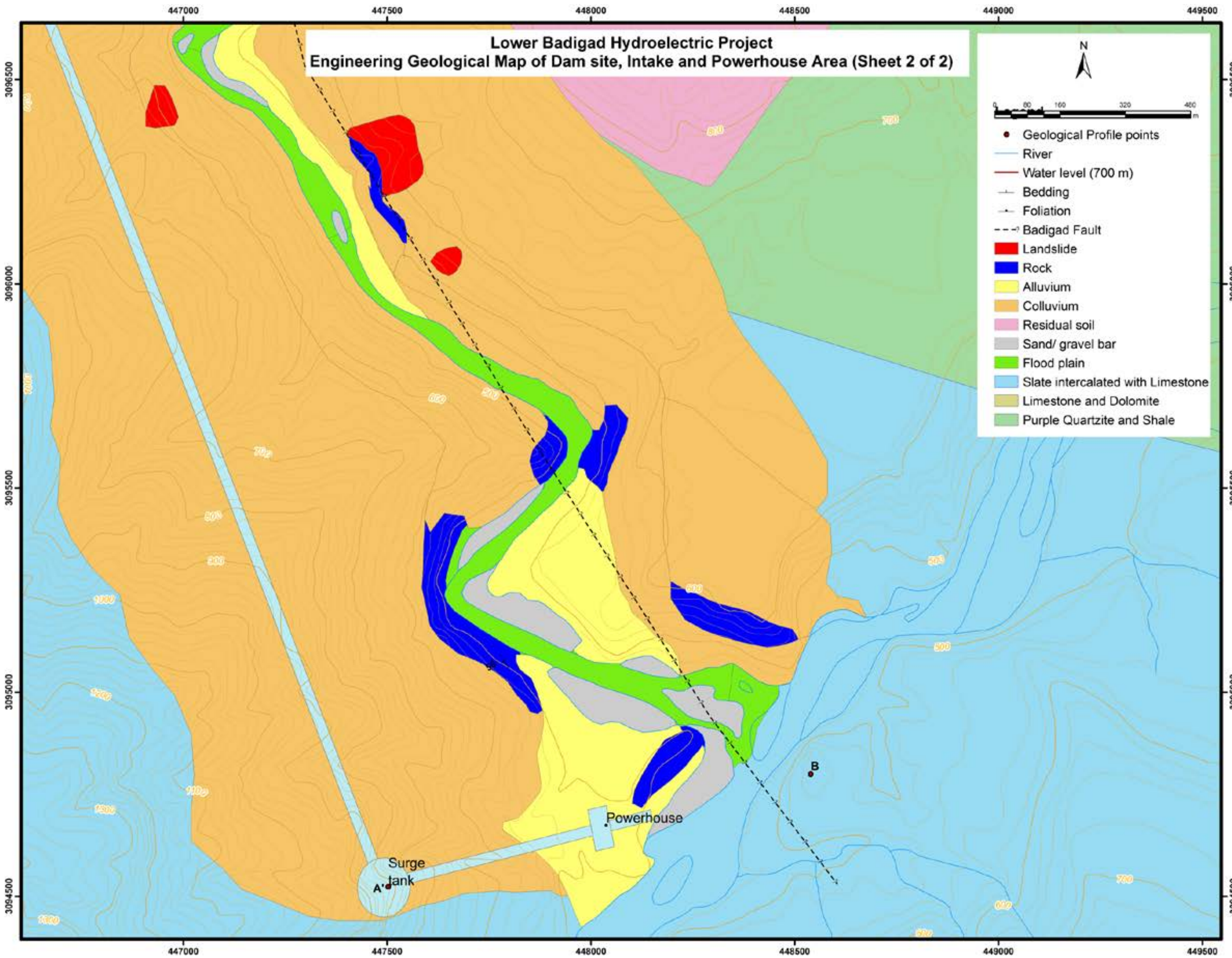

Figure 1.6: (continued): Engineering geological map of dam site, intake, water route and powerhouse area.

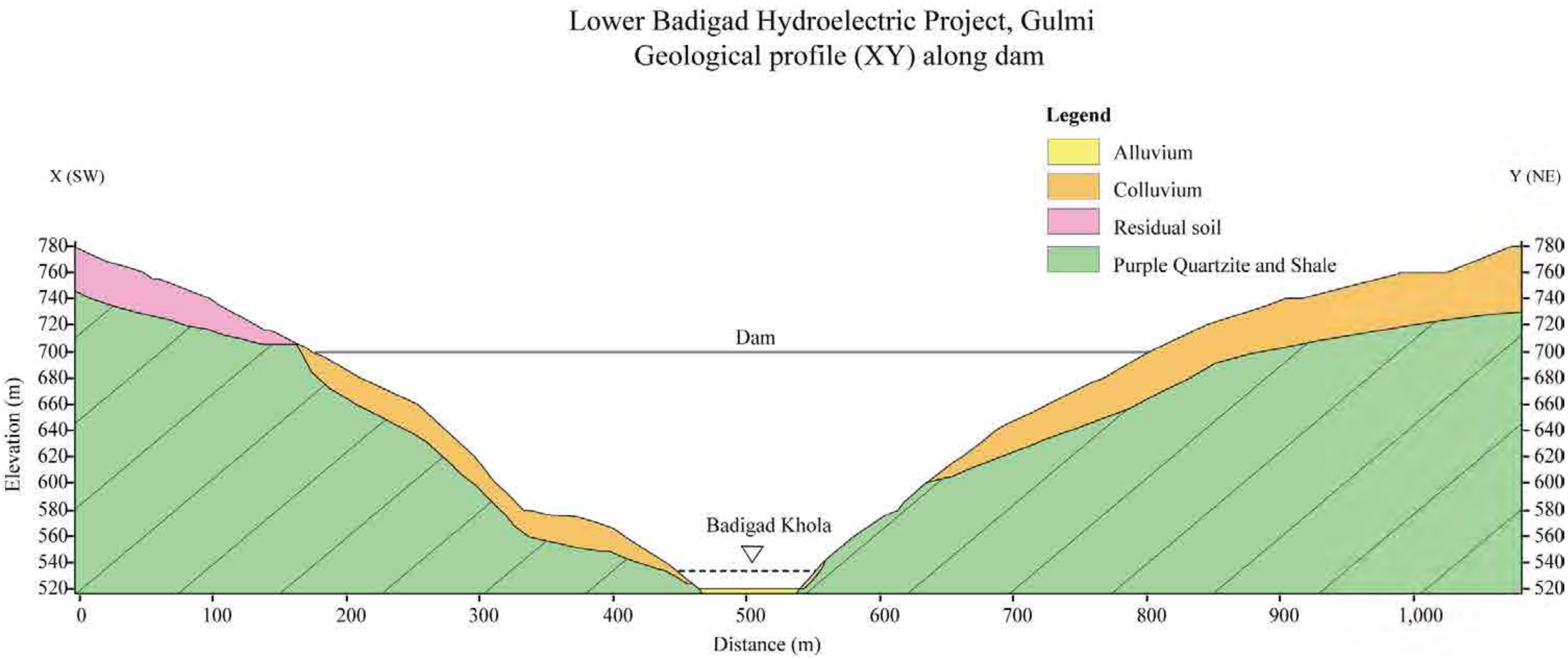

Figure 1.7: Geological profile (XY) along dam

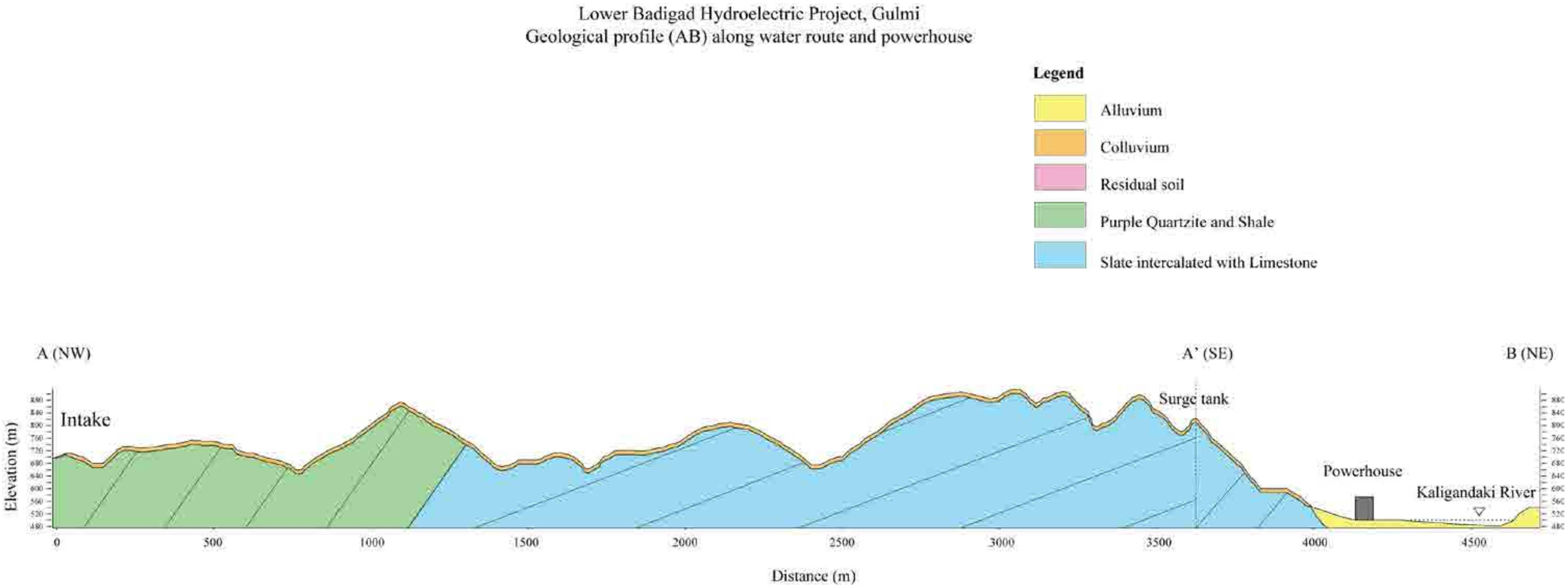

Figure 1.8: Geological profile (AB) along water route and powerhouse.

1.7 Construction materials

The study was also made to identify the suitable sites for the construction materials in the vicinity of the project site. The estimation of different materials is carried out by visual inspection at this phase of study and the study confirmed that the quantity and quality of different construction materials available in the project area are suitable for the project. The required amount of gravel, sand, and fines is available near the upstream of the dam site (Figures 1.3 and 1.13) and near the confluence of the Badigad Khola and Kaligandaki River. Also the quartzites around dam site could be good sources of boulders and gravel.

1.8 Further recommendations

The Badigadhydroelectric project is geologically sound and feasible. However some further investigations are required to assess the dam site for permeability of limestone and shales, investigation of the headrace tunnel alignment for its stability, and study of channel shifting in the powerhouse area.

Figure 1.9: Downstream view of the Lower Badigad dam site, at waypoint WPT088. View to S.

Figure 1.10: Light grey, laminated and fractured shales at the dam site, at waypoint WPT081.

Figure 1.11: Landslide (GhultungPahiro) shows dolomite overlying black shales in the reservoir area. Photo taken at waypoint WPT062 at Kimkot, View to N.

Figure 1.12: Alluvial fan at the left bank of BadigadKhola near GultungPahiro, taken at waypoint WPT063. Note that Gultung Pahiro has deposited huge amount of sediment at the river valley of BadigadKhola. View to NE.

Figure 1.13: The alluvial terrace, sand and gravel bar as a source of construction material, upstream of dam site, taken at waypoint WPT085. View to W from dam site.

Figure 1.14: Powerhouse site on the alluvial terrace of BadigadKhola at RudrabeniGaun, taken at waypoint WPT095. View to E.

Figure 1.15: Landslide on colluvial terrace observed on the left bank of the BadigadKhola near the village of Kumal, taken at waypoint WPT034. View to NE.

1.9 GPS survey and photos

Fieldwork was carried out for five days. During the field work primary geological data was collected throughout the project area. Since each group had three geologists and only one GPS, the two geologists put the observation points directly on the map without the help of GPS, based on ground truth. The GPS data and photos are already submitted. The location points are presented in Table 1.1 and the major attitude of bedding/foliation are presented in Table 1.2. GPS locations are shown in Figure 1.16 while submitted photograph numbers and their locations are shown in Figure 1.17.

Table 1.1: GPS locations in the Lower Badigad hydroelectric project area

TYPE	IDENT	LAT	LONG	TIME	ALTITUDE	Photo No.
WAYPOINT	015	27.97581076	83.46771975	10-JUL-12 10:25:57	483.00	
WAYPOINT	016	27.97586935	83.46751641	10-JUL-12 10:36:43	485.00	
WAYPOINT	017	27.97589910	83.46754817	10-JUL-12 11:53:46	489.00	
WAYPOINT	018	28.13286751	83.31004676	10-JUL-12 15:39:25	713.00	5498, 5499
WAYPOINT	019	28.12479322	83.31937348	10-JUL-12 17:01:28	689.00	5504
WAYPOINT	020	28.12078357	83.31648608	10-JUL-12 17:34:28	704.00	5506
WAYPOINT	021	28.11952083	83.31435523	10-JUL-12 17:54:15	703.00	5508
WAYPOINT	022	28.11860369	83.31368862	10-JUL-12 18:03:35	717.00	
WAYPOINT	023	28.11857653	83.31288136	10-JUL-12 18:09:05	721.00	
WAYPOINT	024	28.12314567	83.31974865	11-JUL-12 6:24:14	682.00	5511
WAYPOINT	025	28.12200012	83.32278315	11-JUL-12 6:37:24	690.00	5512
WAYPOINT	026	28.11609331	83.32834957	11-JUL-12 7:08:28	668.00	
WAYPOINT	027	28.11521203	83.32992788	11-JUL-12 7:24:57	658.00	5522, 5523
WAYPOINT	028	28.10950102	83.33430399	11-JUL-12 7:40:19	663.00	
WAYPOINT	029	28.10721109	83.33452209	11-JUL-12 7:50:21	668.00	
WAYPOINT	030	28.10538928	83.33303556	11-JUL-12 8:01:34	672.00	5528, 5529
WAYPOINT	031	28.10164676	83.33518652	11-JUL-12 8:58:10	686.00	
WAYPOINT	032	28.09918097	83.33080530	11-JUL-12 9:50:31	647.00	5536
WAYPOINT	033	28.09953704	83.33398213	11-JUL-12 10:09:17	661.00	
WAYPOINT	034	28.09690872	83.33720782	11-JUL-12 10:24:18	649.00	
WAYPOINT	035	28.09557608	83.33579966	11-JUL-12 10:41:58	654.00	5549
WAYPOINT	036	28.09187036	83.33669166	11-JUL-12 11:02:06	641.00	
WAYPOINT	037	28.08789491	83.33919483	11-JUL-12 14:21:04	663.00	
WAYPOINT	038	28.08946450	83.34077449	11-JUL-12 14:31:09	663.00	5560
WAYPOINT	039	28.08090792	83.34579701	11-JUL-12 14:52:16	666.00	
WAYPOINT	040	28.07757494	83.34766081	11-JUL-12 15:17:10	657.00	
WAYPOINT	041	28.07530621	83.34726300	11-JUL-12 15:31:59	645.00	5576, 5577
WAYPOINT	042	28.06980601	83.34945386	11-JUL-12 15:52:17	634.00	5586, 5587
WAYPOINT	043	28.07003140	83.35229784	11-JUL-12 16:47:36	649.00	
WAYPOINT	044	28.07187147	83.35296731	11-JUL-12 16:57:27	649.00	5590
WAYPOINT	045	28.07445570	83.35525732	11-JUL-12 17:05:58	661.00	
WAYPOINT	046	28.06710058	83.34699243	11-JUL-12 18:07:10	633.00	5600
WAYPOINT	047	28.06768673	83.34445565	11-JUL-12 18:21:33	647.00	
WAYPOINT	048	28.06895876	83.34485362	11-JUL-12 18:49:49	645.00	
WAYPOINT	049	28.06677863	83.35248551	12-JUL-12 6:16:10	633.00	
WAYPOINT	050	28.06646883	83.35771129	12-JUL-12 6:34:29	666.00	5611, 5612
WAYPOINT	051	28.05912805	83.36624357	12-JUL-12 6:57:17	613.00	5613
WAYPOINT	052	28.05459679	83.36700473	12-JUL-12 7:25:19	628.00	
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WAYPOINT	054	28.05088989	83.36984955	12-JUL-12 7:58:26	616.00	
WAYPOINT	055	28.04794458	83.37944674	12-JUL-12 8:34:01	624.00	5631
WAYPOINT	056	28.04756907	83.38048325	12-JUL-12 8:45:11	624.00	
WAYPOINT	057	28.04791323	83.38359050	12-JUL-12 9:03:57	611.00	
WAYPOINT	058	28.05492938	83.38417430	12-JUL-12 10:08:43	639.00	5639
WAYPOINT	059	28.05641801	83.38441017	12-JUL-12 10:19:36	648.00	
WAYPOINT	060	28.04536823	83.39019620	12-JUL-12 13:18:17	605.00	
WAYPOINT	061	28.04045292	83.39492988	12-JUL-12 14:11:26	647.00	5649
WAYPOINT	062	28.04066380	83.39678211	12-JUL-12 14:24:36	657.00	

TYPE	IDENT	LAT	LONG	TIME	ALTITUDE	Photo No.
WAYPOINT	063	28.03615929	83.40313962	12-JUL-12 15:07:23	616.00	5656, 5657
WAYPOINT	064	28.03641217	83.40634645	12-JUL-12 15:22:46	658.00	
WAYPOINT	065	28.03380766	83.41047160	12-JUL-12 15:58:41	601.00	
WAYPOINT	066	28.03250578	83.41009618	12-JUL-12 16:16:21	600.00	
WAYPOINT	067	28.03991396	83.40628836	13-JUL-12 6:56:58	627.00	5670
WAYPOINT	068	28.04106396	83.40658802	13-JUL-12 7:05:18	636.00	
WAYPOINT	069	28.03375485	83.41535616	13-JUL-12 8:05:17	580.00	5678
WAYPOINT	070	28.03270812	83.41994030	13-JUL-12 8:23:13	603.00	
WAYPOINT	071	28.02884901	83.42283365	13-JUL-12 8:49:04	604.00	5880
WAYPOINT	072	28.02391014	83.44122598	13-JUL-12 10:08:54	652.00	
WAYPOINT	073	28.02739140	83.44457899	13-JUL-12 10:23:43	693.00	5690
WAYPOINT	074	28.02353379	83.44434178	13-JUL-12 10:47:52	654.00	
WAYPOINT	075	28.02182917	83.44391858	13-JUL-12 11:03:09	651.00	5694
WAYPOINT	076	28.01460623	83.44009509	13-JUL-12 14:15:28	599.00	
WAYPOINT	077	28.01323998	83.44165631	13-JUL-12 14:26:33	597.00	
WAYPOINT	078	28.01173333	83.44420524	13-JUL-12 14:45:45	576.00	5703
WAYPOINT	079	28.00972452	83.45176606	13-JUL-12 15:09:54	532.00	5707, 5708
WAYPOINT	080	28.00866388	83.45153161	13-JUL-12 15:25:12	531.00	
WAYPOINT	081	28.00682941	83.45238908	13-JUL-12 15:32:08	533.00	5714, 5715
WAYPOINT	082	28.00575754	83.45622724	13-JUL-12 15:52:10	544.00	
WAYPOINT	083	28.00663940	83.45848155	13-JUL-12 16:04:51	576.00	
WAYPOINT	084	28.00811746	83.45873913	13-JUL-12 16:21:47	589.00	
WAYPOINT	085	28.00312981	83.45461724	13-JUL-12 17:32:26	545.00	5722, 5723
WAYPOINT	086	28.00195131	83.45458589	13-JUL-12 17:50:18	535.00	
WAYPOINT	087	28.00077659	83.45459570	13-JUL-12 18:08:32	531.00	5732
WAYPOINT	088	27.99922829	83.45675983	14-JUL-12 9:11:47	555.00	5733
WAYPOINT	089	27.99881715	83.46119536	14-JUL-12 9:24:57	519.00	
WAYPOINT	090	27.99357712	83.46101230	14-JUL-12 9:52:02	499.00	
WAYPOINT	091	27.99135131	83.46220681	14-JUL-12 10:03:15	521.00	
WAYPOINT	092	27.98516463	83.46379819	14-JUL-12 10:22:51	524.00	5745, 5746
WAYPOINT	093	27.97904181	83.46992176	14-JUL-12 11:09:03	516.00	
WAYPOINT	094	27.97402642	83.46709681	14-JUL-12 11:23:47	480.00	5757
WAYPOINT	095	27.97204426	83.46828410	14-JUL-12 11:36:06	487.00	5759, 5760

Table 1.2: GPS locations with attitude of bedding, foliation and joints in the Badigad hydroelectric project area

Waypoint	Strike	Dip Amount	Dip Direction	Type
19	178	46	S	F
20	340	56	S	F
23	355	54	S	B
24	350	40	S	B
29	130	80	N	B
30	325	71	S	F
33	160	55	S	F
40	140	54	N	F
42	150	58	S	F
43	178	58	S	F
45	128	72	S	F
46	340	38	S	F
48	155	50	S	F
49	320	64	S	F
51	170	50	S	F
53	10	35	N	F
54	209	42	N	F
56	230	43	N	F
58	20	46	N	F
59	335	60	S	F
60	345	38	S	F
61	158	45	S	F
62	295	50	S	F
63	195	45	S	B
65	77	27	N	B
66	215	50	N	B
67	315	32	S	B
69	250	40	N	F
70	36	28	N	B
74	150	34	S	F
76	225	60	N	F
77	210	30	N	F
78	10	45	N	F
79	110	40	N	F
81	248	61	S	F
83	85	40	N	F
85	336	60	N	F
86	141	51	S	F
87	280	42	S	F
88	315	57	S	F
89	30	80	N	F
90	295	60	S	F
91	327	77	N	F
93	126	73	S	F
94	325	56	S	F

Table 1.3: Geological Study Team Members and Itinerary of the Field Visits

Name of Project	District	Date of field visit	Name of the Geologlist	Investigation method
Lower badigad	Gulmi	9th July - 15th July, 2012	Dr. Sunil K. Dwivedi Mr. Lalit Rai Mr. Gautam Khanal	Geological reconnaissance survey

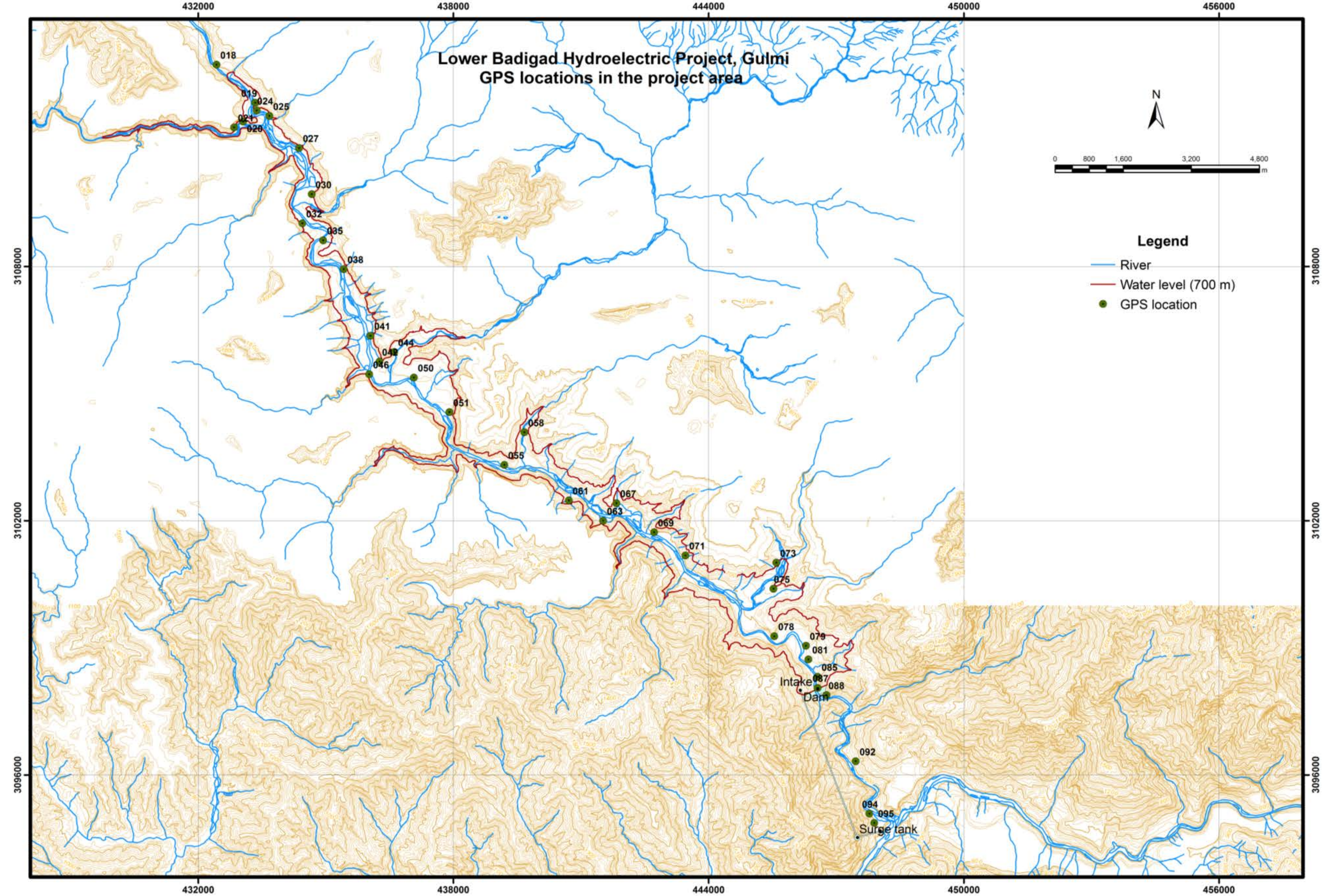

Figure 1.16: GPS locations in the Lower Badigad hydroelectric project.

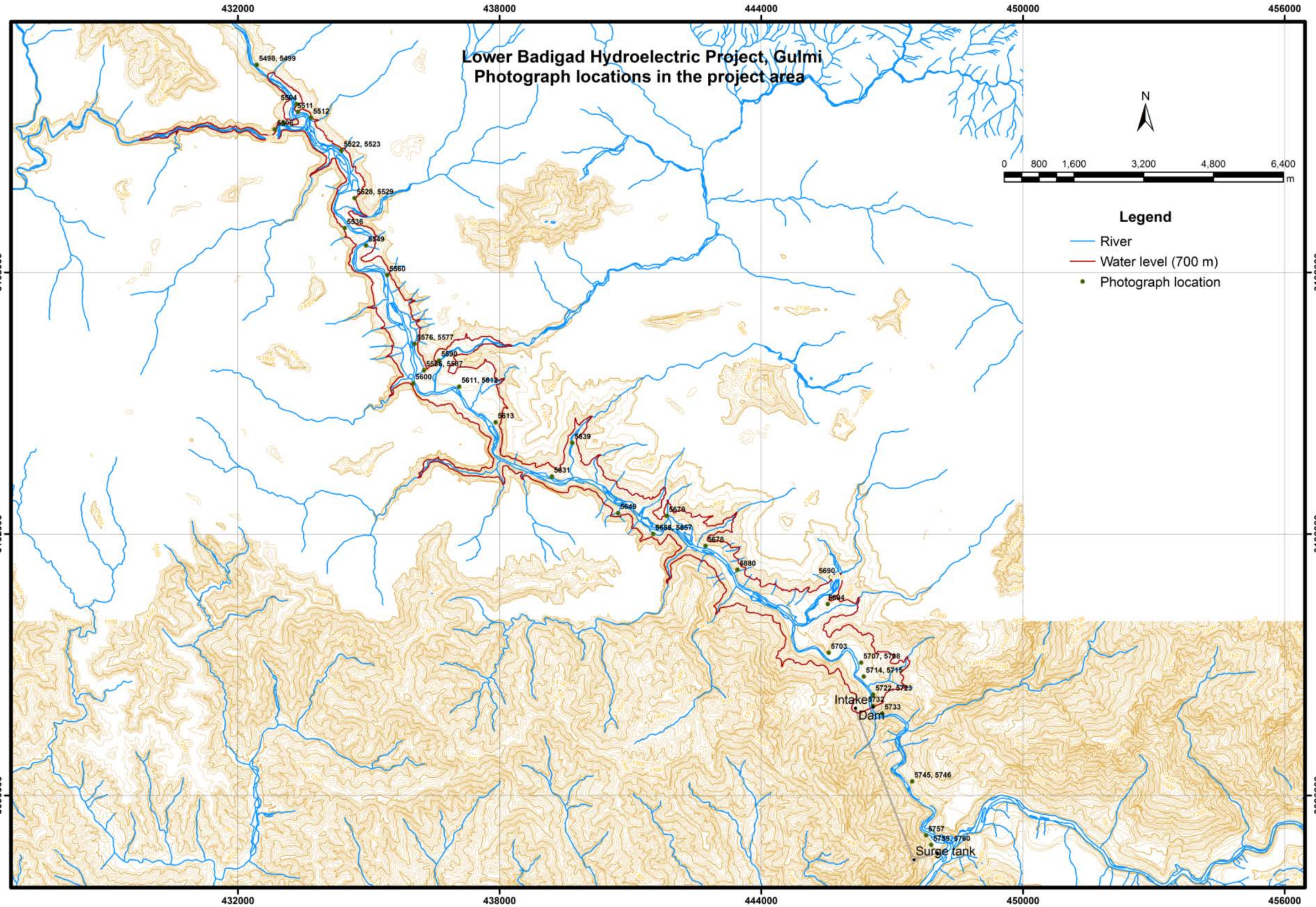

Figure 1.17: Photograph numbers with their locations in the project area.

Annex 5: Geological Survey Report

Andhi Khola Project (C-08)

Table of Contents

Introduction

This Report deals with the engineering geological investigations in the Andhi Khola hydroelectric dam projects. This project area was surveyed by Dr Subesh Ghimire, Mr Asim Rijal and Mr. Yogendra Mohan Shrestha between 9 and 15 July 2012. Geology and engineering geology of this project are summarized below.

1 Andhi Khola Project

The Andhi Khola Reservoir Project is located in Syangja District of Central Nepal. The project covers middle reaches of the Andhi Khola Khola. The dam site is proposed near the Chheda village and the powerhouse lies in the lowe reaches of the AndhiKhola.

1.1 Geology of project area

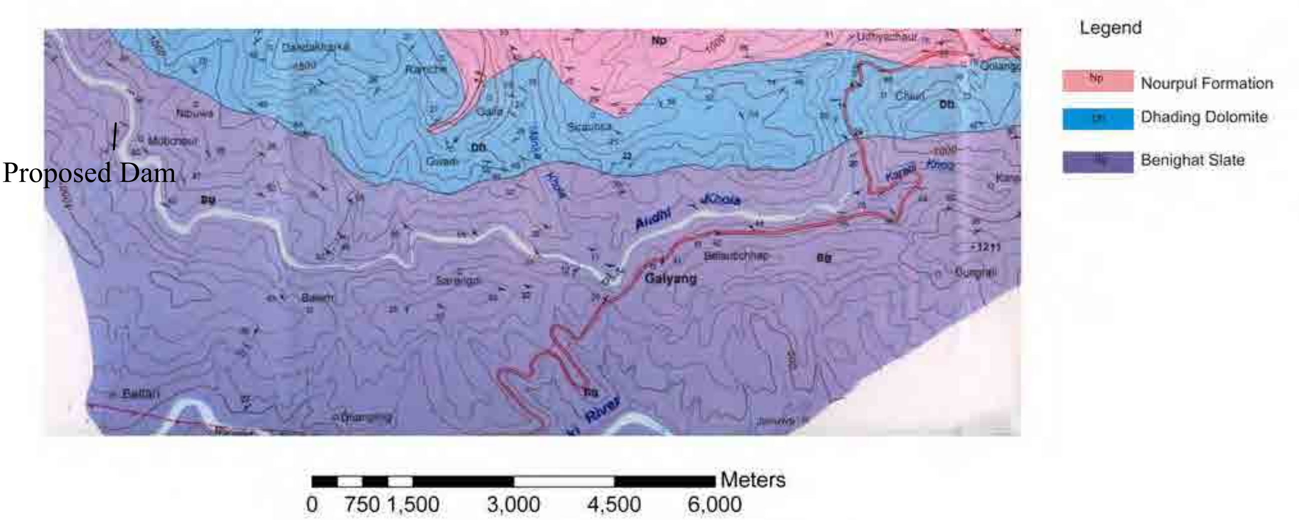

Figure 1.1: Regional geological map in and around the project area.

The project area is comprised of metasedimentary rocks of the Lesser Himalaya with slates, sandstones, and dolomites. The geological map prepared by the Department of Mines and Geology of Government of Nepal (Figure 1 1) divides the lithology of the Lesser Himalaya of this area into three formations namely: Nourpul Formation, Dhading Dolomite and Benighat Slate. The location of the observation points in the area is shown in Figure 1.2 and Table 1.1.

Lithology: The main lithology is comprised of gray to dark, laminated slate with fewer intercalation of carbonate bands at the lower part (Figure 1.3). This lithology is comparable with the Benighat Slate with grey to dark grey laminated slate (Figure 1.4). The lithology gradually changes to a thick succession of thick bedded, bluish grey, stromatolitic dolomite correlatable with the Dhading Dolomite of Central Nepal. The contact between the Dhading Dolomite and the Benighat Slate is gradational (Figure 1.5) where small scale folds are abundant

Quaternary deposits: Colluvial deposits, and debris flow deposits (alluvial fans) are found on the valley floors of the Andhi Khola its main tributaries. The colluvial deposits predominate on upper moderately steep to gentle slopes and spurs.

The alluvial deposits are distributed in the lower reaches of the Andhi Khola and they are less than 10 m thick.
Rock mass condition: The dolomite in the upper reaches of the AndhiKhola is comparatively strong but it may suspect the water tightness due to the probable cavern structures. The rocks of the Benighat slate are highly fractured and fragile and very weak. The slates exhibit crenulation cleavage (Figure 1.6)

Weathering: Water and air are the main sources of weathering. Apart from them, sunshine (temperature variation) has also played a significant role in weathering of quartzites. The overall weathering depth in rocks reaches up to 7 m and sometimes more than that.

Jointing: Three discontinuity sets are seen in the Benighat Slate, the three sets are almost perpendicular to each other, especially in quartzites. The slates are characterized by very irregular joints. The joints are straight to slightly wavy in the quartzites, where their aperture ranges from less than 1 mm to 5 mm, but some joints are rather wide (up to 1 cm) and continue for several tens of metres.

Stability conditions: The rock and soil slopes in the project area are generally unstable. The main source of sediments is the debris flow in the Andhi Khola from its tributaries due to the wedge failure of the surrounding slopes.
The highest flood level in the Andhi Khola is about 2.5 to 3 m from the general flow level. Owing to the frequent debris flows from the tributary streams, the water in the Andhi Khola becomes excessively turbid most of the time in the monsoon season. Hence, some measures are required to deal with this problem. On the other hand, it is clean and clear during the dry period.

Groundwater conditions: The Andhi Khola is the only perennial whereas its tributaries are seasonal. The rocks in the area are pervious such that major control on seepage should be considered.

1.2 Dam axis

The proposed dam axis (Figure 1.7) lies in the pink, medum grained metasandstone is exposed on both banks of the Andhi Khola (Figure 1.8). The rock is categorised as good or fair.

The area around the dam axis is stable and the Andhi Khola has a more or less straight course to the downstream of that area where the slopes are dry. A landslide near the proposed dam axis is a serious problem for its stability.

1.3 Reservoir

The reservoir covers an area of about 200 sq. km along the Andhi Khola from Udiyachaur in the northeast to Sarun in the southwest (Figure 1.2). Tallo Galyang, Pelli, Sera, Matichaur, Illunga and Sarun are the major settlements prone to inundation after the construction of the high dam.
The lithology is comprised of the low grade metasedimentary rocks of the Lesser Himalaya, colluvial and alluvial deposits in most of the reservoir area (more than 90% of the reservoir area). Besides this residual soil deposits are also abundant in the area. On the upper reaches of the reservoir the lithology gradually changes to very thick bedded, massive, bluish grey dolomite. The alluvial deposit constitutes the river terraces along the Andhi Khola which are mostly used for cultivation by the local people. Besides the river terraces, the alluvium deposits are found as the alluvial fans. These alluvial terraces are a few centimetre to more than two meter thick. The colluvial deposit on the other hand, is found on the hill slopes on both banks of the Andhi Khola. These colluvium deposits are the result of landslides and gully erosion. The predominating lithology in the reservoir is comprised of slates that are highly weathered and in some cases

changed to residual soil. As a result the hill slopes on both banks of the Andhi Khola are highly unstable as manifested by many landslides in the study area (Figure 1.9).

1.4 Powerhouse

The proposed powerhouse site is located on the left bank of the Kaligandaki River on its alluvial terrace (Figure 1.10, 1.11). On the uphill side the lithology is comprised of light gray, carbonaceous slate. The site is quite suitable for the given project.

1.5 Water way

An intake tunnel (Figure 1.12, 1.13) is proposed on the left bank of the Andhi Khola, about 3km upstream of the dam. The area is made up of slate and metasandstone, it has a moderately steep rock cliff.

The proposed tunnel passes basically through the slates of the Benighat Slate. The overburden along the proposed headrace tunnel varies from less than 50 m to about 700 m. Owing to the gentle dip of rock beds some precautions are required during construction to overcome roof collapse.

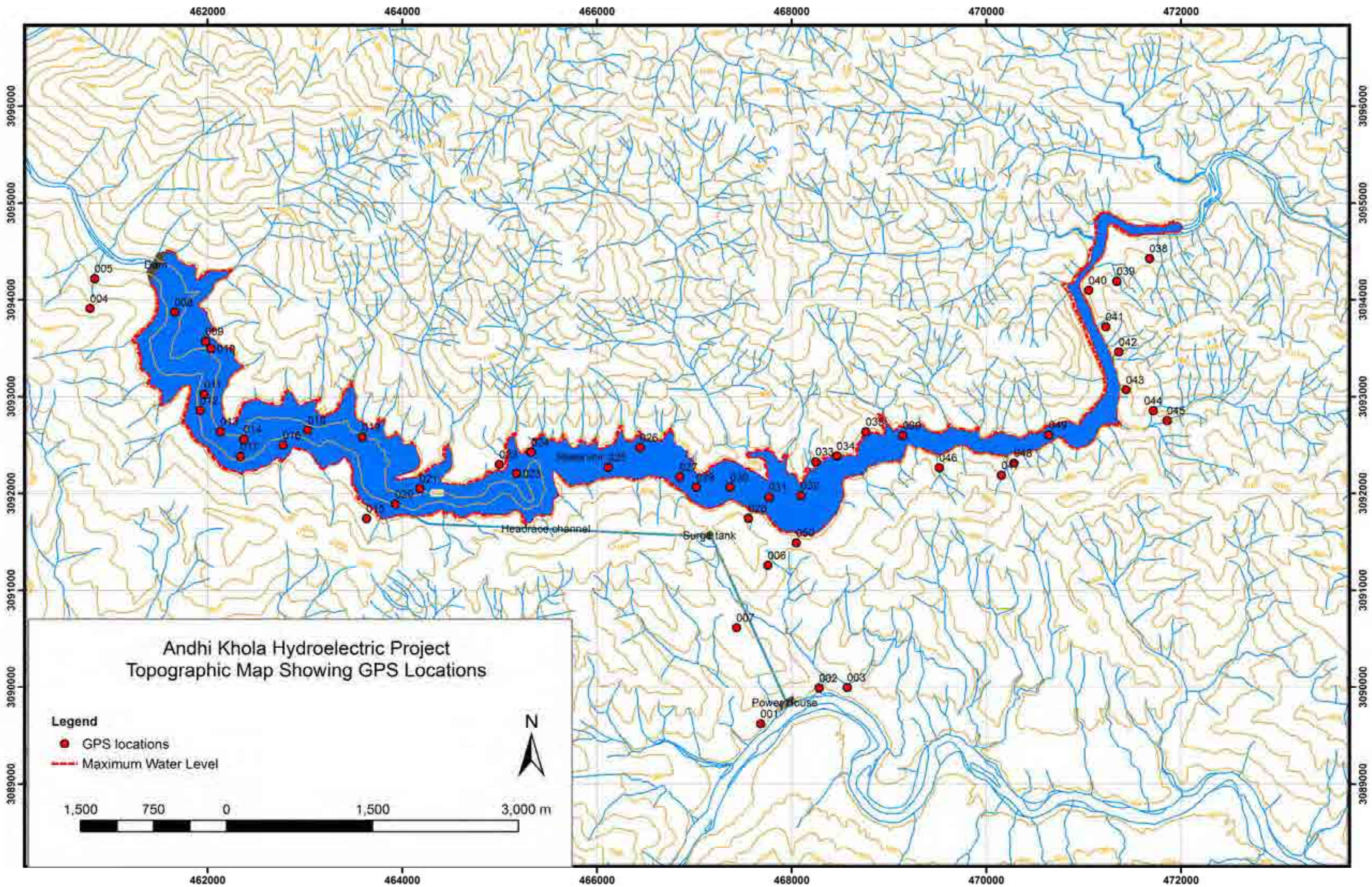

Figure 1.2: Topographic Map Showing the location of different observation points

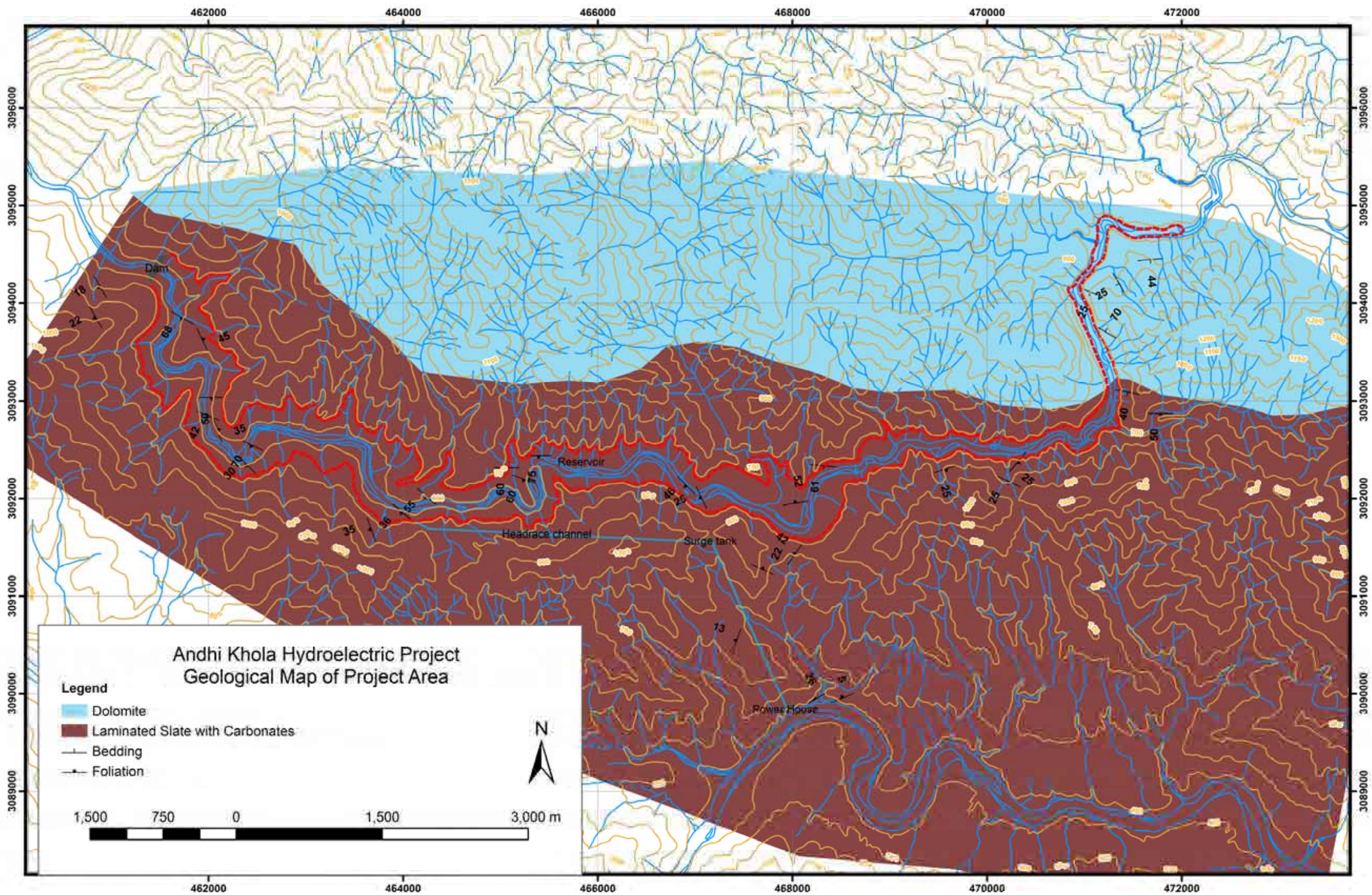

Figure 1.3: Detailed geology of the project area

Figure 1.4: Photograph showing the laminated slates on the Siddhartha Highway, near Galyang Bazaar (Location 28)

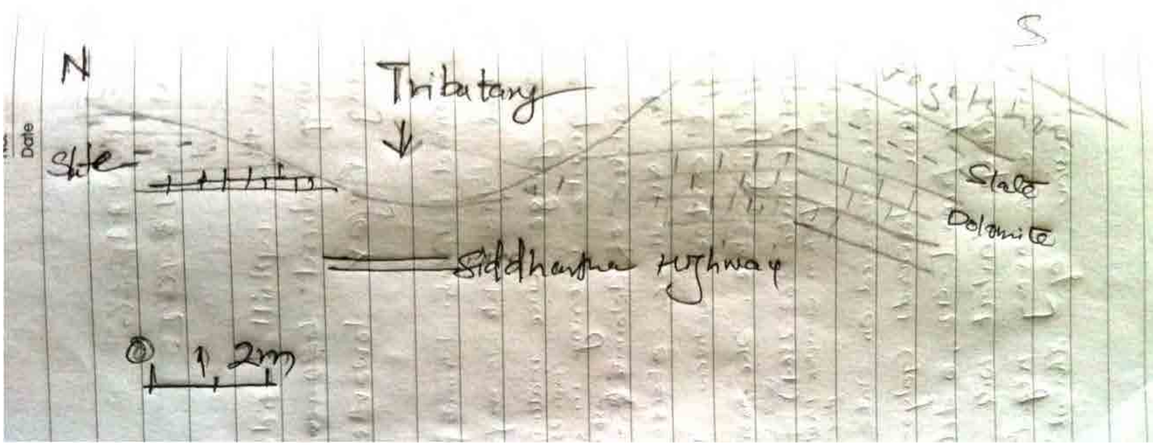

Figure 1.5: Sketch illustrating the gradational contact and the small scale fold near location no 42 (Figure 7.2 and Table 7.1).

Figure 1.6: Photograph illustrating crenulation cleavage in Benighat Slate near location no 32 (Figure 1.2 and Table 1.1).

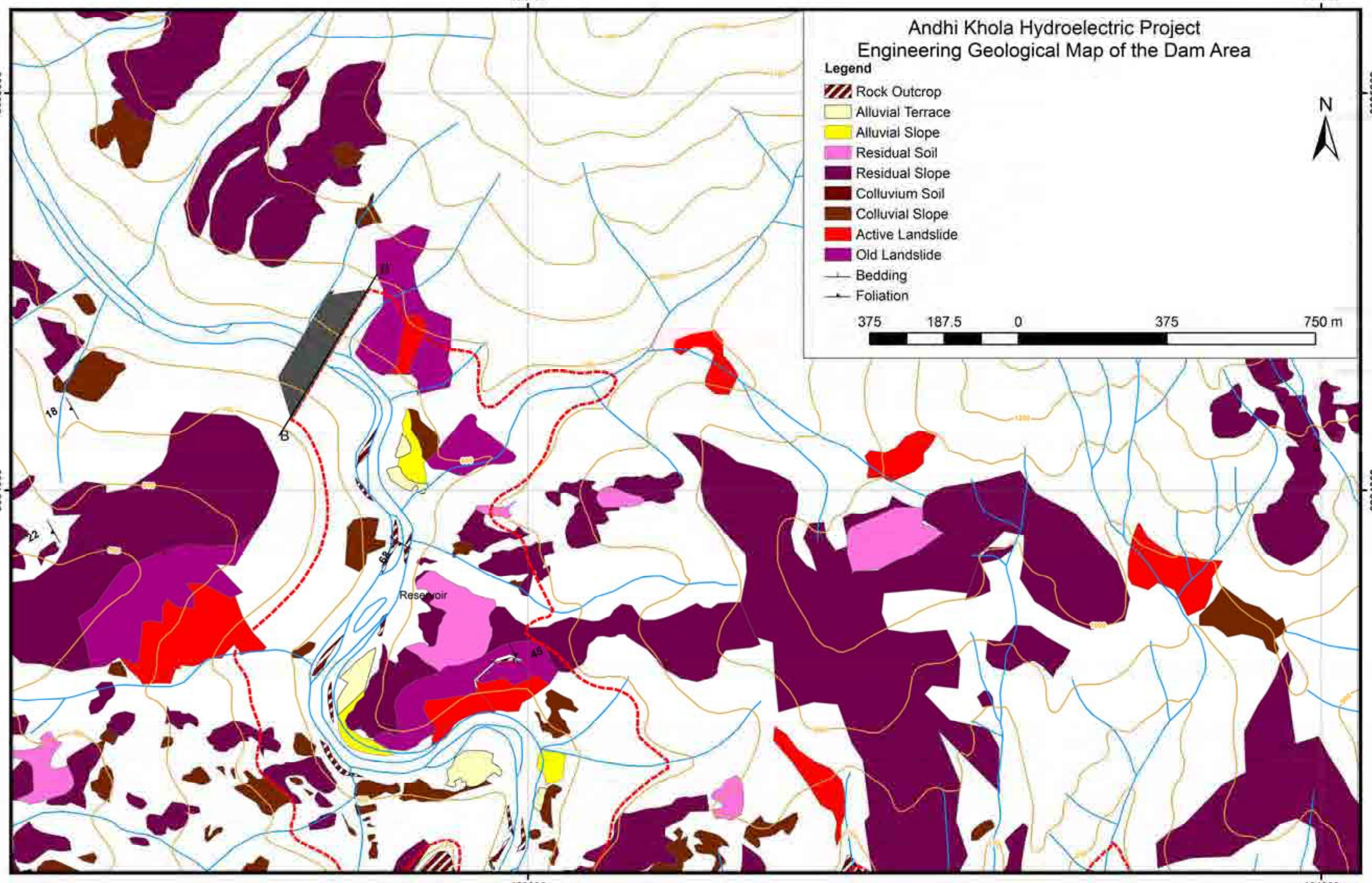

Figure 1.7: Engineering Geological Map of the Dam Area. Line BB' shows the line of cross section

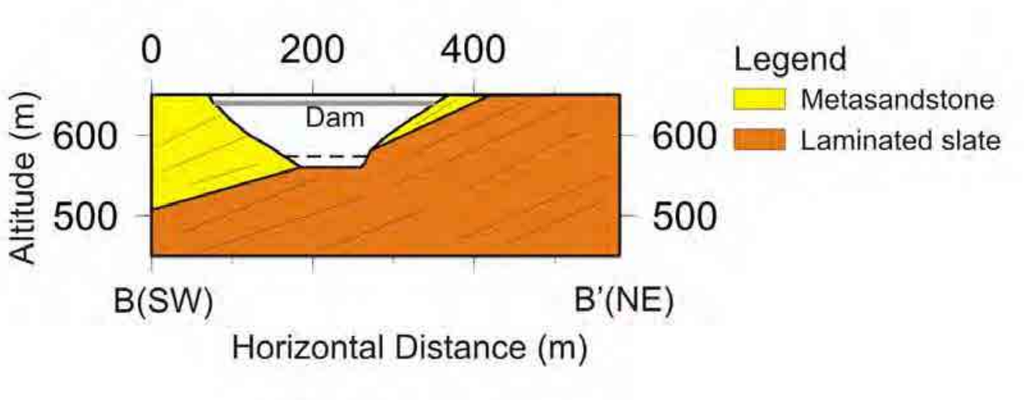

Figure 1.8: Geological cross section along DD' in the dam area.

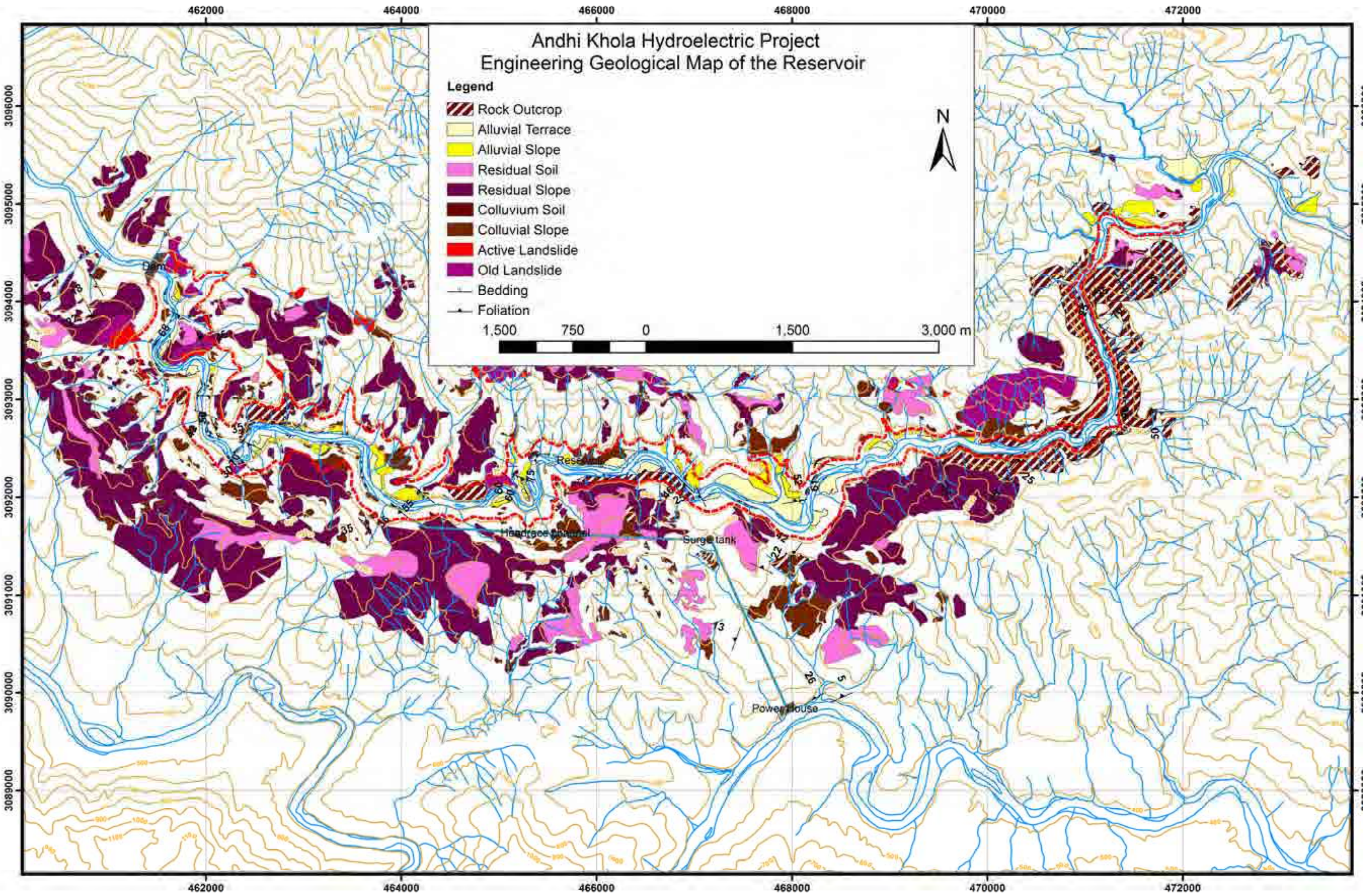

Figure 1.9: Engineering geological map of the reservoir area

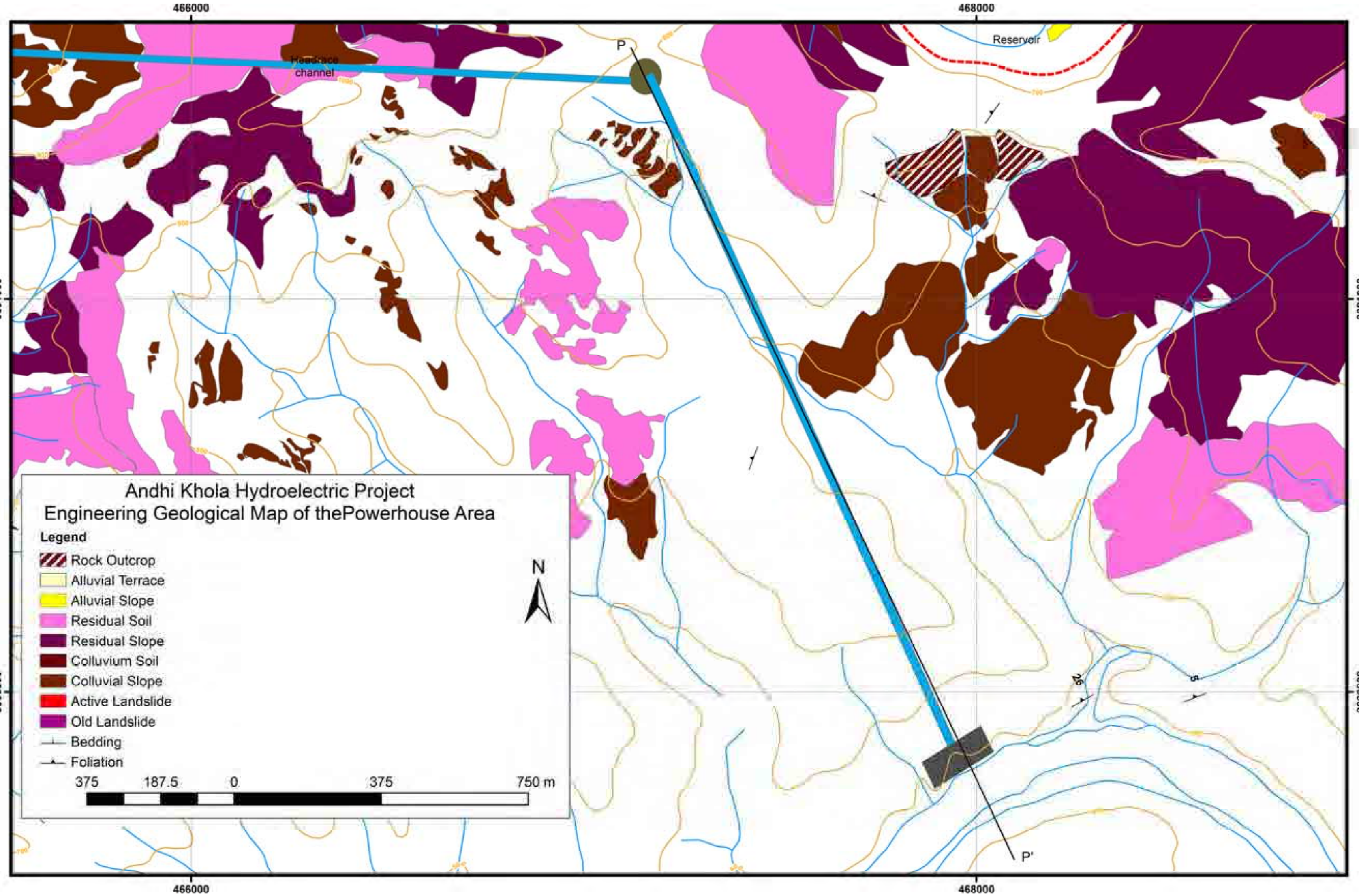

Figure 1.10: Engineering geological map of the powerhouse area. Line PP' shows the line of cross section

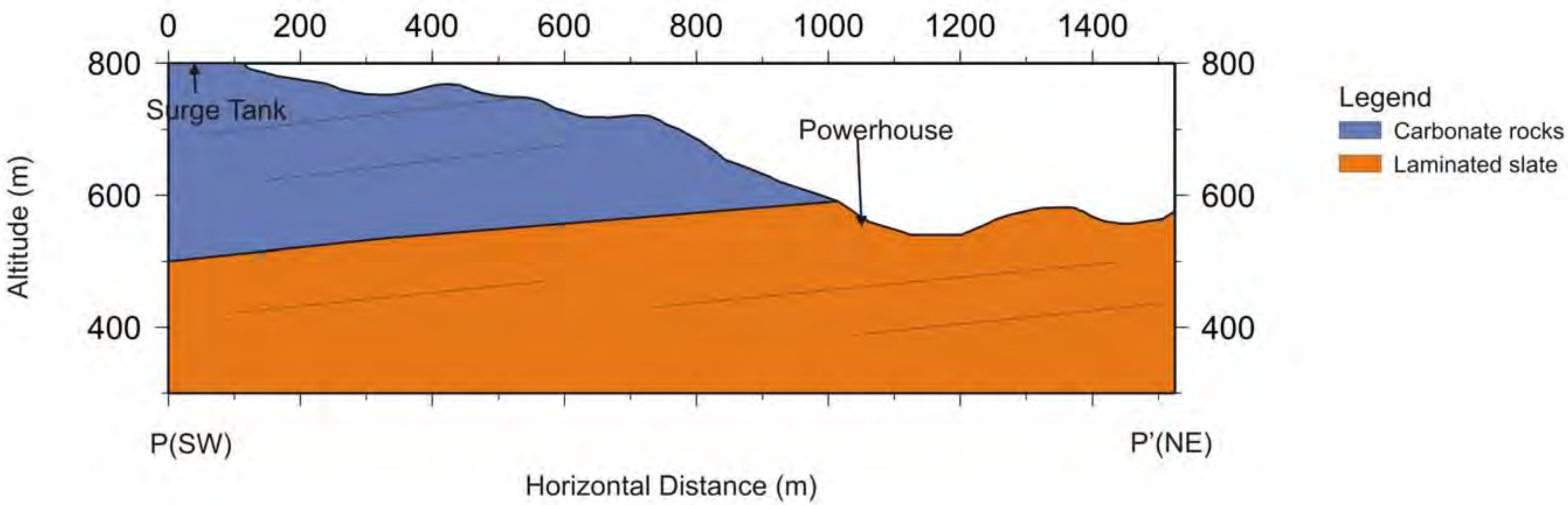

Figure 1.11 Geological cross section along PP' in the powerhouse area

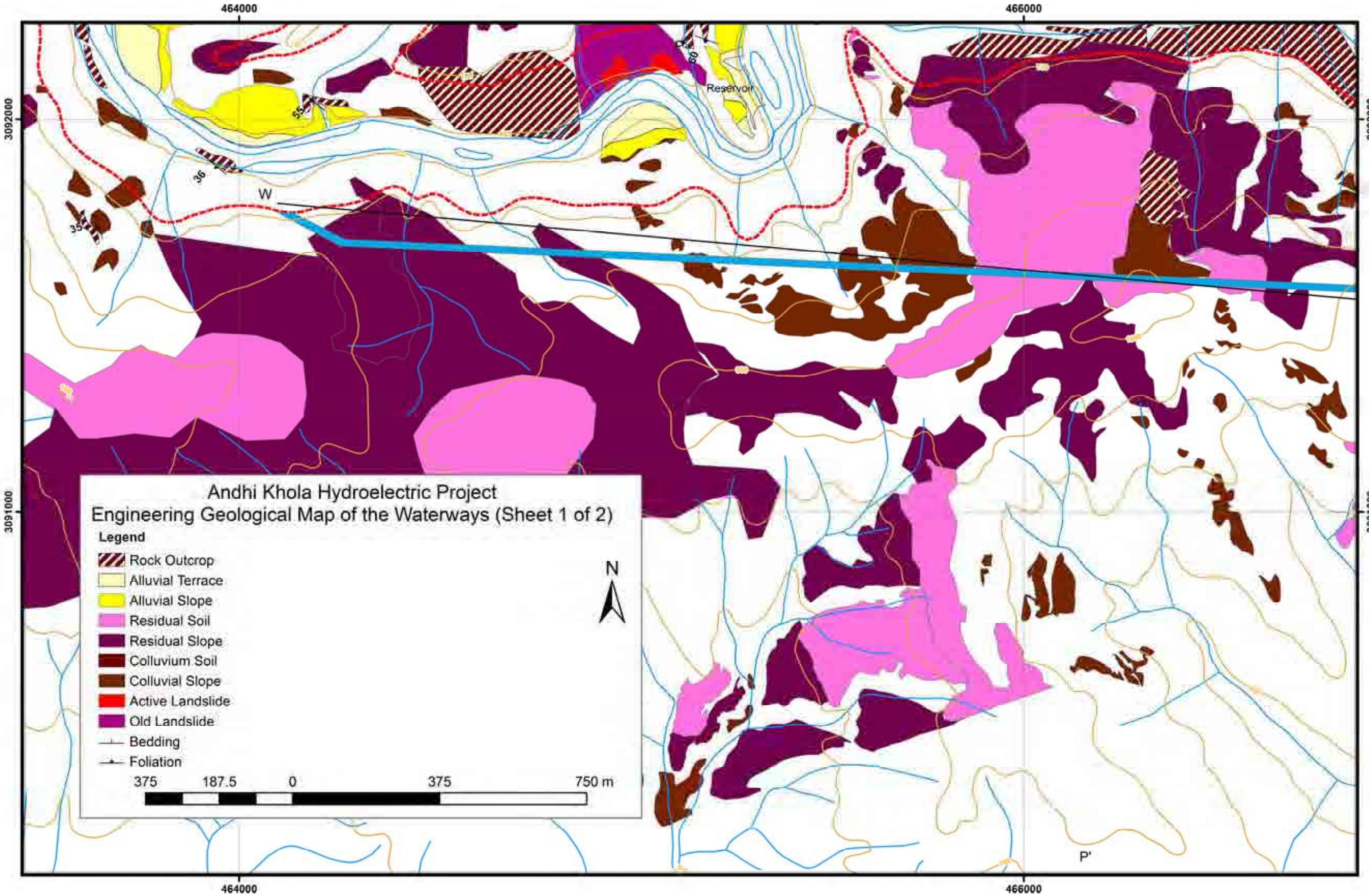

Figure 1.12 Engineering geological map of the waterway. Line WW' shows the line of cross section.

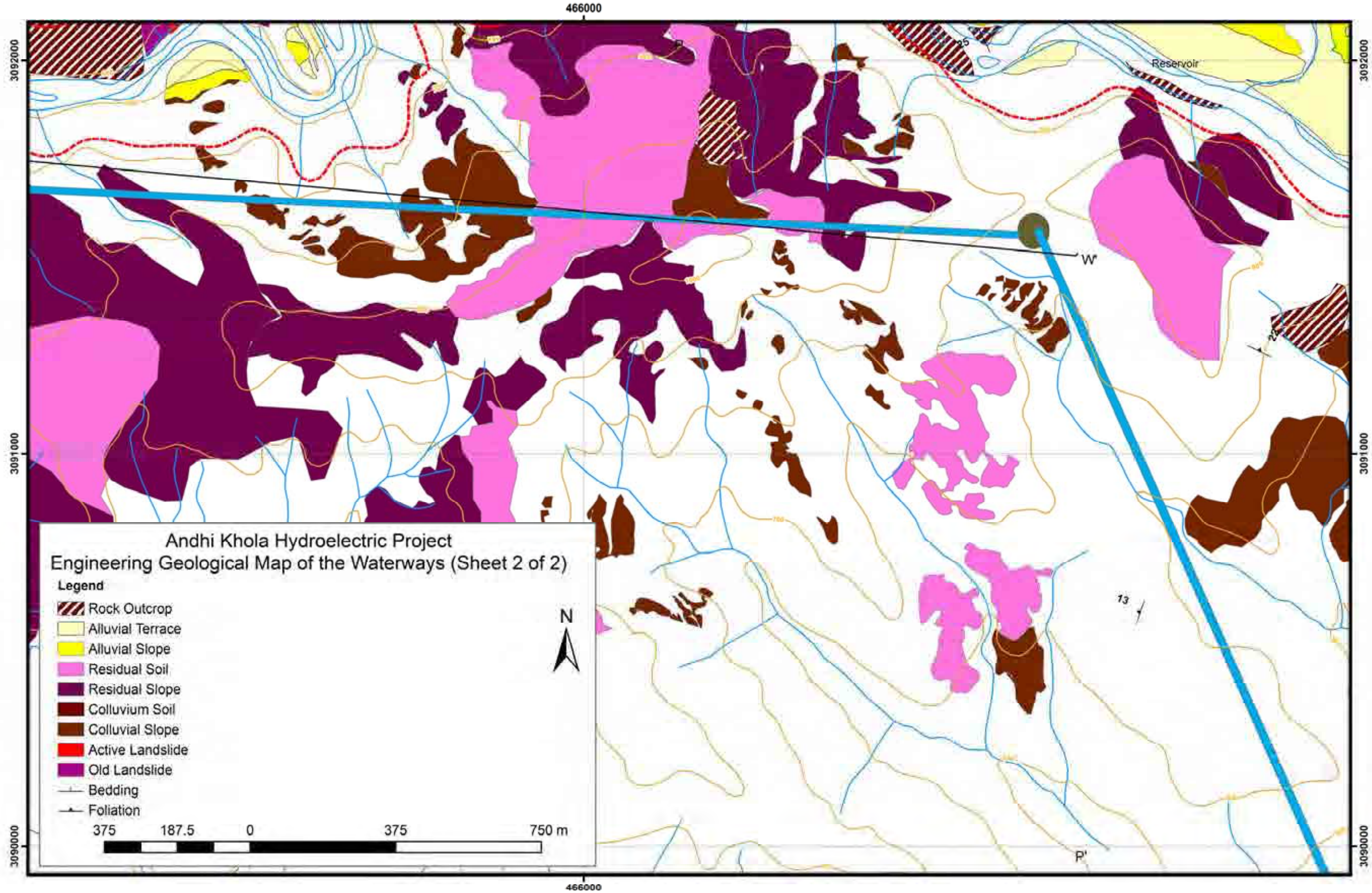

Figure 1.12: Engineering geological map of the waterway.(Continued)

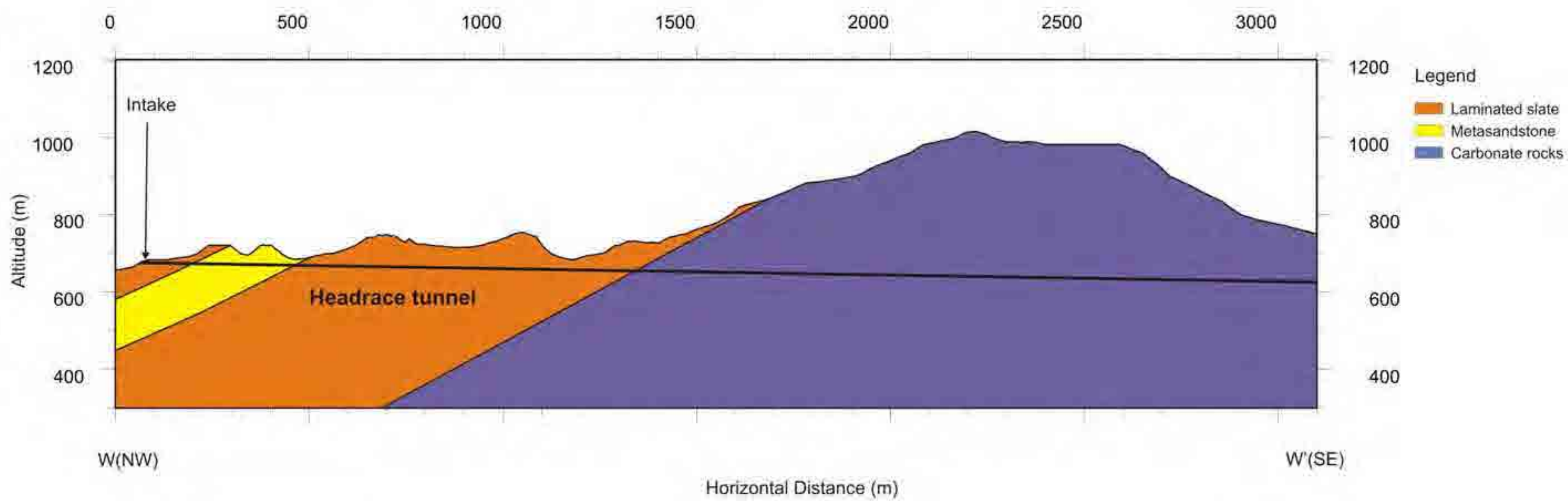

Figure 1.13: Cross section along WW'

1.6 Instabilities

Many small and large landslides are common in the reservoir area. The previously proposed dam site is located in an unstable zone with many landslides on the left bank of the Andhi Khola. The slates are highly fragile and intensely deformed such that many recent landslides are common along the newly constructed road alignments (Figure 1.14). A large landslide is also observed in the powerhouse site. A landslide near the proposed dam site has threatened the stability of the proposed dam (Figure 1.15).

Figure 1.14 Photograph showing a large landslide on highly weathered slate (almost converted to residual soil) near location 034 (Figure 7.2).

Figure 1.15: Landslide about 50m upstream from the proposed dam site. View to Northeast

1.7 Construction materials

The required amount of coarse aggregate is available in the Andhi Khola near the Matichaur village about 500m upstream from the previously identified dam site (Figure 1.16). The fines should be obtained from the alluvial terraces of the Andhikhola River near Sera and Illunga. In the vicinity of dam site, boulders constitute about 40% of the total, whereas cobbles are also about 40%, and pebbles constitute the remaining 20% of the total volume. The coarse aggregate is composed mainly of quartzites, slates, and dolomites. The construction material is enough for building the dam and related structures.

Figure 1.16: Upstream view of the Andhi Khola near Matichaur showing coarse aggregates

1.8 Further recommendations

The Andhi Khola hydroelectric project is geologically sound and feasible. However some further investigations are required to access the dam site and the headrace tunnel for stability.

1.9 GPS survey and photos

Since each group had three geologists and only one GPS, the two geologists put the observation points directly on the map without the help of GPS, based on ground truth. The GPS data and photos are already submitted.

Table 1.1 Observations sites and their locations

TYPE	IDENT	LAT	LONG	ALTITUDE	TIME	Photographs
WAYPOINT	001	27.92537000	83.66953800	434.37	2012-07-10T02:18:32Z	91-98
WAYPOINT	002	27.92871400	83.67565000	359.09	2012-07-10T03:06:16Z	101-103
WAYPOINT	003	27.92877800	83.67857000	436.44	2012-07-10T04:08:02Z	-
WAYPOINT	004	27.96388300	83.59940300	830.75	2012-07-10T08:37:05Z	
WAYPOINT	005	27.96667800	83.59987100	691.47	2012-07-11T01:42:31Z	109-113
WAYPOINT	006	27.94014000	83.67023900	690.41	2012-07-11T01:42:48Z	-
WAYPOINT	007	27.93431400	83.66700300	631.83	2012-07-11T02:16:24Z	-
WAYPOINT	008	27.96357700	83.60824700	565.32	2012-07-11T06:06:09Z	122-133, 146
WAYPOINT	009	27.96086300	83.61145800	629.13	2012-07-11T07:59:23Z	167-170
WAYPOINT	010	27.96019100	83.61202900	617.25	2012-07-11T08:20:01Z	-
WAYPOINT	011	27.95590400	83.61136600	568.07	2012-07-11T08:46:05Z	174-184
WAYPOINT	012	27.95442600	83.61094200	557.22	2012-07-11T09:28:52Z	-
WAYPOINT	013	27.95246200	83.61305300	570.29	2012-07-11T09:52:08Z	-
WAYPOINT	014	27.95175400	83.61550000	558.78	2012-07-11T10:17:35Z	-
WAYPOINT	015	27.94439900	83.62832900	748.78	2012-07-12T03:26:00Z	200-202
WAYPOINT	016	27.95119400	83.61959900	638.11	2012-07-12T04:08:50Z	209-212
WAYPOINT	017	27.95014000	83.61513500	561.77	2012-07-12T04:50:10Z	-
WAYPOINT	018	27.95259900	83.62217000	579.01	2012-07-12T07:17:03Z	221-222
WAYPOINT	019	27.95197200	83.62786200	578.72	2012-07-12T07:17:10Z	-
WAYPOINT	020	27.94573700	83.63133800	596.48	2012-07-12T07:40:53Z	226-229
WAYPOINT	021	27.94720200	83.63388300	604.71	2012-07-12T08:02:35Z	235-236
WAYPOINT	022	27.94947100	83.64218400	709.20	2012-07-12T09:34:51Z	-
WAYPOINT	023	27.94862800	83.64399200	635.54	2012-07-12T09:56:53Z	-
WAYPOINT	024	27.95061700	83.64549900	612.74	2012-07-12T10:14:50Z	-
WAYPOINT	025	27.94924200	83.65355400	605.82	2012-07-12T10:51:25Z	-
WAYPOINT	026	27.95107100	83.65686300	608.24	2012-07-12T11:06:19Z	-
WAYPOINT	027	27.94835500	83.66102100	602.31	2012-07-12T11:23:36Z	-
WAYPOINT	028	27.94452400	83.66821400	744.53	2012-07-13T02:38:49Z	-
WAYPOINT	029	27.94741600	83.66275700	608.88	2012-07-13T03:33:59Z	262-263

TYPE	IDENT	LAT	LONG	ALTITUDE	TIME	Photographs
WAYPOINT	030	27.94741600	83.66629300	603.48	2012-07-13T04:00:15Z	264-265
WAYPOINT	031	27.94647700	83.67033900	616.10	2012-07-13T04:15:17Z	276-279
WAYPOINT	032	27.94665900	83.67368300	622.54	2012-07-13T06:13:55Z	280-282, 285
WAYPOINT	033	27.94980200	83.67520000	677.10	2012-07-13T06:39:59Z	297-300
WAYPOINT	034	27.95034800	83.67741600	674.47	2012-07-13T06:57:17Z	303-309
WAYPOINT	035	27.95261400	83.68043600	680.68	2012-07-13T07:20:28Z	320-321
WAYPOINT	036	27.95227000	83.68430400	640.58	2012-07-13T07:37:29Z	324, 328
WAYPOINT	038	27.96882900	83.71001900	789.16	2012-07-13T09:52:08Z	-
WAYPOINT	039	27.96669900	83.70659500	806.80	2012-07-13T10:13:56Z	-
WAYPOINT	040	27.96584900	83.70367400	804.28	2012-07-13T10:30:05Z	341-342
WAYPOINT	041	27.96245300	83.70545400	781.74	2012-07-13T11:05:04Z	346-350, 352-353
WAYPOINT	042	27.96010500	83.70683200	767.37	2012-07-13T11:36:27Z	-
WAYPOINT	043	27.95657400	83.70759500	768.47	2012-07-13T12:25:27Z	-
WAYPOINT	044	27.95464900	83.71044700	752.40	2012-07-13T13:04:33Z	-
WAYPOINT	045	27.95373400	83.71188300	743.36	2012-07-13T13:13:25Z	-
WAYPOINT	046	27.94928100	83.68810700	778.14	2012-07-14T03:03:38Z	-
WAYPOINT	047	27.94858300	83.69460200	764.30	2012-07-14T03:02:17Z	-
WAYPOINT	048	27.94972800	83.69591400	734.90	2012-07-14T03:20:03Z	-
WAYPOINT	049	27.95236000	83.69953800	632.01	2012-07-14T03:53:13Z	396-409
WAYPOINT	050	27.94223800	83.67320600	705.34	2012-07-14T04:43:39Z	-

Table 1.2: Attitude of Bedding (B)/Foliation (F) at observation sites

Way Point	Strike	Dipdirec	Dip Angle	Type
002	60	NW	26	F
003	68	NW	5	F
004	330	SW	22	F
005	330	SW	18	F
006	115	NE	22	F
007	20	NW	13	F
008	120	SW	68	F
009	155	NE	45	F
011	270	S	50	F
012	112	SW	42	F
013	160	NE	35	F
014	115	SW	70	F
015	160	SW	35	F
017	315	SW	30	F
020	130	SW	36	F
021	310	SW	55	F
022	270	S	60	F
023	290	SE	60	F
024	270	S	75	F
027	315	SW	46	F
029	155	SW	25	F
032	260	NW	52	F
033	95	SW	61	F
037	295	SW	34	B
038	85	SE	44	B
039	330	SE	25	B
040	290	SW	25	B
041	120	NE	70	B
043	100	SW	40	B
044	270	S	50	F
046	252	SE	25	F
047	295	SW	25	F
048	220	SE	25	F
050	35	NW	42	F

Table 1.3: Geological Study Team Members and Itinerary of the Field Visits

Name of Project	District	Date of field visit	Name of the Geologlist	Investigation method
Andhi khola	Syanja	9th July - 15th July, 2012	Dr. Subesh Ghimire Mr. Asim Rijal Mr. Yogendra Mohan Shrestha	Geological reconnaissance survey

Annex 6: Geological Survey Report

Chera-1 Project (W-02)

Table of Contents

Introduction

This Report deals with the engineering geological investigations in the Chera-1 hydroelectric dam projects. This project area was surveyed by Professor Dr Megh Raj Dhital, Mr Narayan Adhikari, and Mr Santosh Adhikari between 8 and 19 July 2012. Geology and engineering geology of this project are summarized below.

1 Chera-1 Project

The Chhera Khola Reservoir Project lies in west Nepal in the Jajarkot Distirct. The project occupies the middle reaches of the Chhera Khola. The dam site is proposed south of Jyula and the powerhouse lies north of Marka, on the left bank of the Chhera Khola.

1.1 Geology of project area

The geological map by the Department of Mines and geology (DMG 1983) shows the Precambrian Lesser and Higher Himalayan rocks (Figure 1.1) represented by the Ranimatta Fm (Rm) of phyllites and quartzites, the Kusma Formation of Quartzites (Ks), carbonates of the Surbang Formation (Sb) and the garnetiferous schists and quartzites of the Siuri Formation (Sr). The rocks also belong to the Chail Formation of Fuchs and Frank (1970) composed mainly of phyllites and quartzites.

Lithology: The Precambrian rocks constituting the Chhera Khola area are represented by phyllies, quartzites, biotite schsits, and garnet schists with a thick band of meta-diamictite in the central part (Figure 1.2). The rocks have undergone two stages of folding and the reservoir area lies mainly in the core of an essentially E–W trending syncline very gently plunging due east (Figures 1.2 and 1.3). The gradational contact between the meta-diamictite and overlying schists and quartzites is depicted in Figures 1.4 and 1.5.

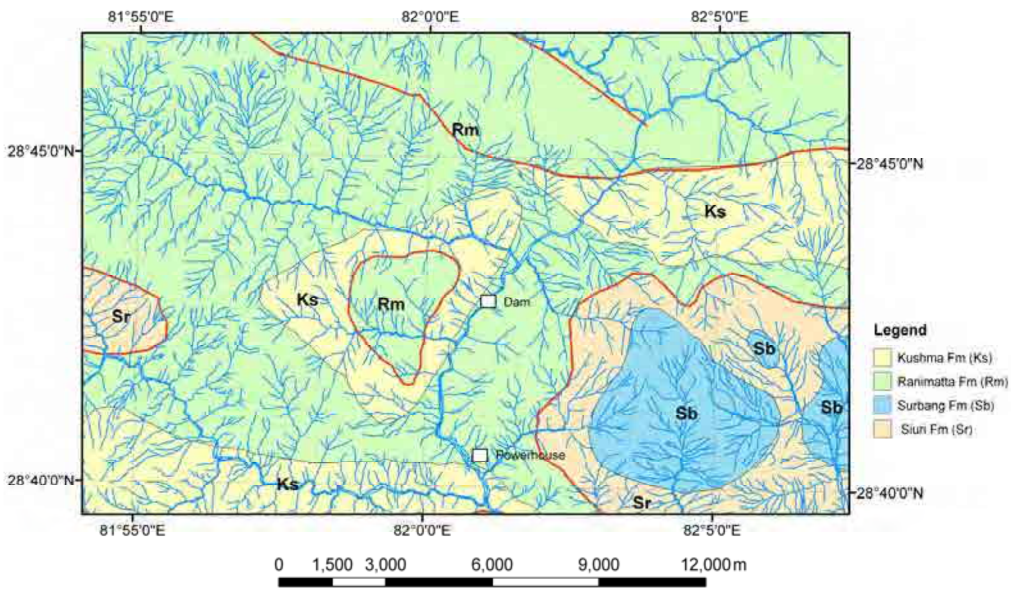

Figure 1.1: Regional geological map of the Chhera Khola area (Modified from DMG 1983).

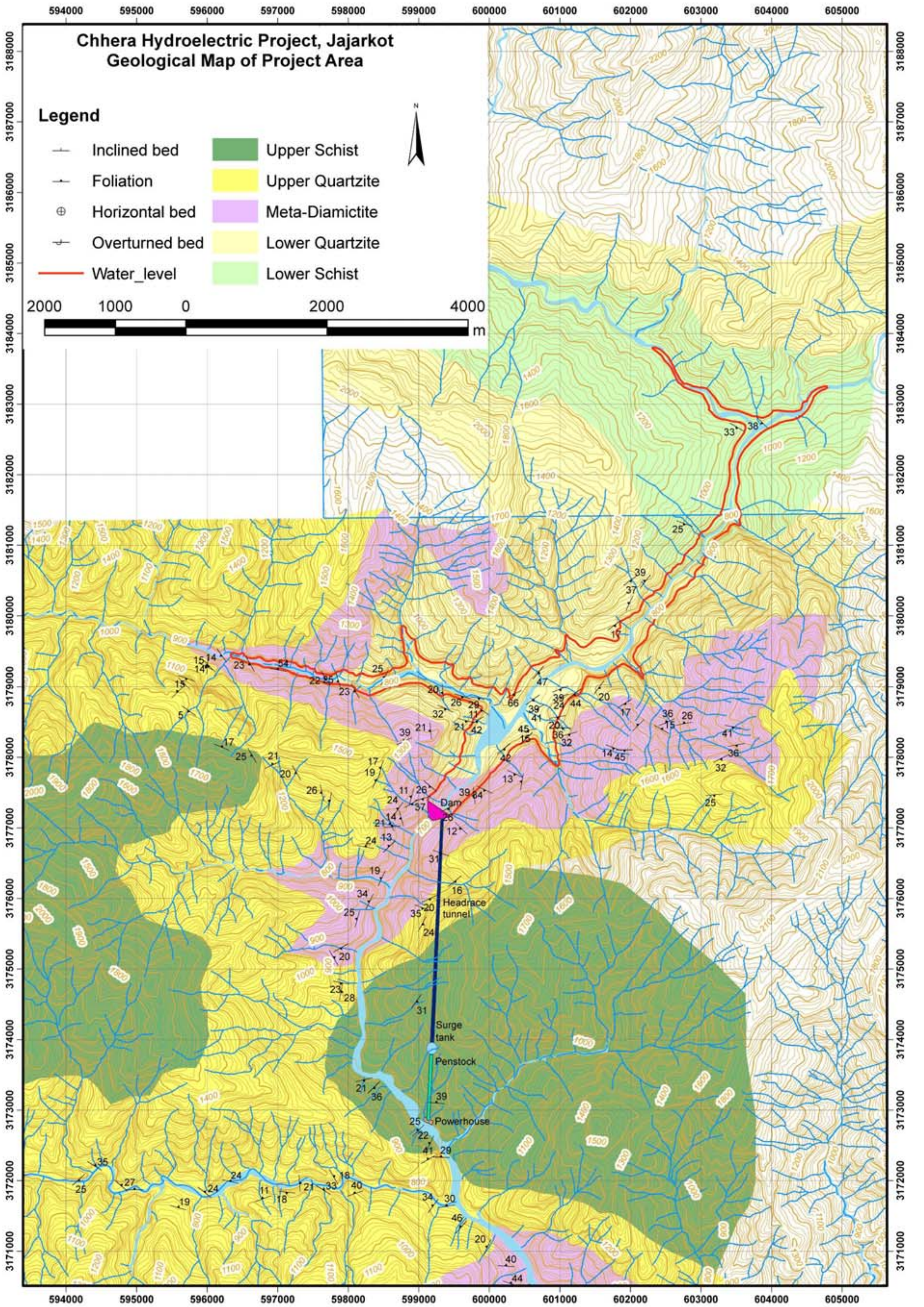

Figure 1.2: Geological map of the Chhera Khola hydropower project area with the dam site, waterway, and the powerhouse site.

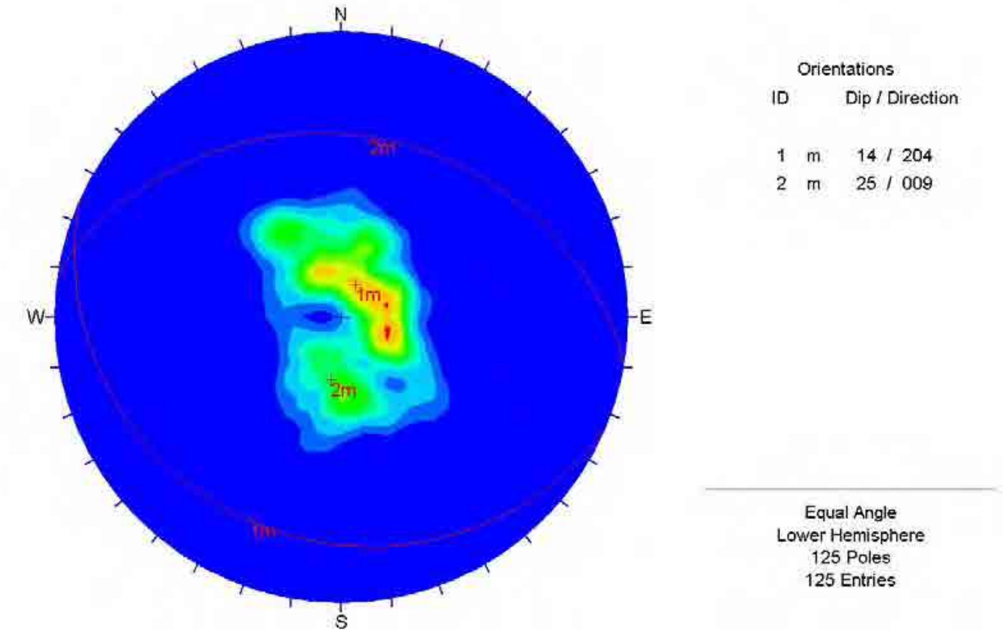

Figure 1.3: Stereographic plot of foliation in the Chhera Khola Hydroelectric project area. The two flanks of a synclinal fold are well represented and the fold is very gently plunging due west.

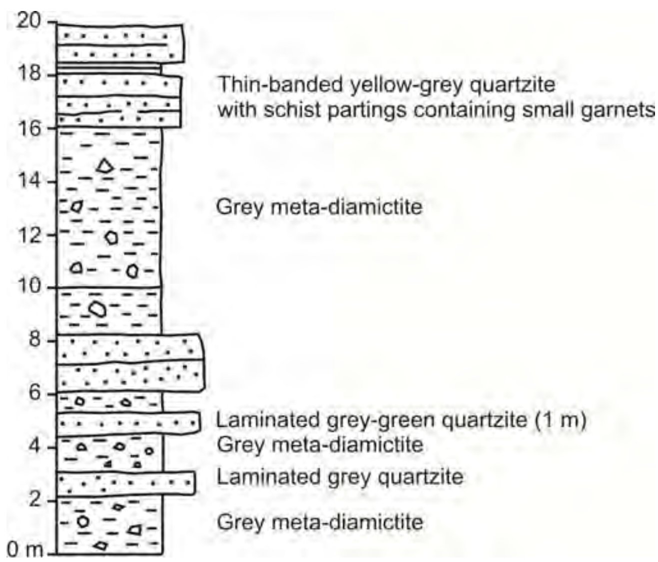

Figure 1.4: Columnar section showing a transitional contact between the meta-diamictite and overlying schist and quartzite exposed on the cliff near Raijobra, on the way to Ahale (WPT 113).

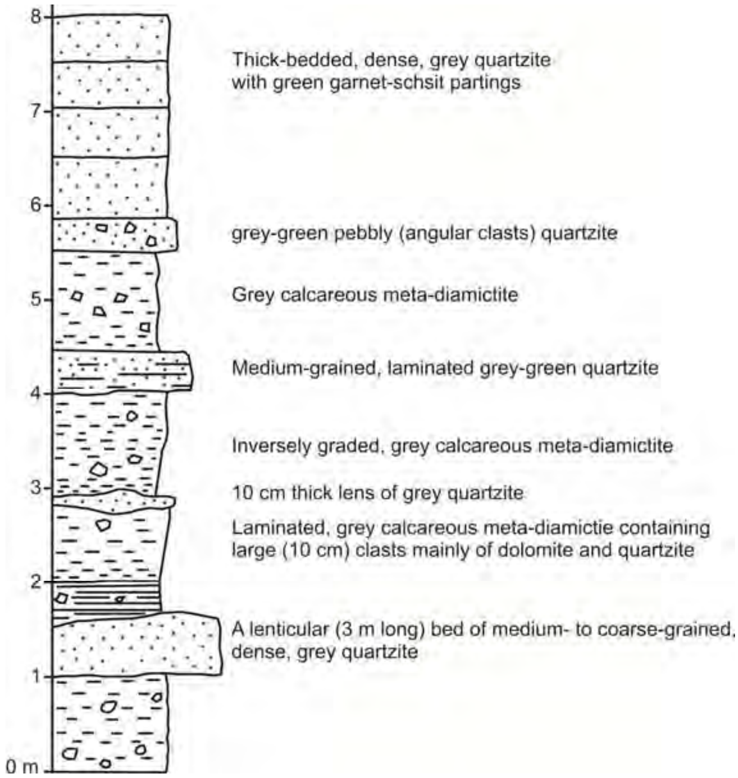

Figure 1.5: Columnar section depicting a transitional contact between the meta-diamictite and overlying schist and quartzite exposed in the road cut of the Madhya Pahadi Rajmarg, near Ratmata (WPT 91).

Quaternary deposits: Talus cones, colluvial deposits, and debris flow deposits (alluvial fans) are found on the valley floors of the Chhera Khola and its main tributaries. The talus cones range in depth from more than 20 or 30 m to less than 1 m. Such fans are developed on the Lower Quartzite near Managar and Jyula, and in the Salma Khola. The colluvial deposits predominate on upper moderately steep to gentle slopes and spurs.

The alluvial deposits are limited in distribution and they are less than 25 m thick. They are seen only near Jyula and around Thalah. The insignificant development of alluvial terraces in the project area points out to active tectonic uplift of the area from the past to the present.

Rock mass condition: The metamorphic rocks of the project are are comparatively strong. The overall stability of the rock mass is good to very good. The resistant quartzites form steep cliffs, gorges, and sharp peaks, whereas the schist form a smooth spur and ridge or gently valley. On the other hand, the meta-diamictite makes steep flanks and smooth tops with well developed vegetation. The two quartzite bands are the stronger rocks, and they are followed by the Lower Schist and the Upper Schsit, whereas the weakest unit is the calcareous meta-diamictite.

Weathering: Water and air are the main sources of weathering. Apart from them, sunshine (temperature variation) has also played a significant role in weathering of quartzites. The overall weathering depth in rocks reaches up to 5 m and sometimes more than that.

Long-term weathering of resistant quartzite bands has resulted into the widespread distribution of talus cones and debris flow fans. The talus cones well developed at Managad contains from 10 cm to 2 m in size angular quartzite blocks. The rounded quartzite blocks and boulders also constitute the alluvial terraces. Weathering of the Lower and Upper Quartzites has developed colluvial soils on the middle slopes, especially around the village of Badaban, where very big (up to 5 m in size) quartzite and schist blocks cover a large area. They could be past rockslide deposits. The weathered garnet schsit and phyllite yield finer colluvial soil and sporadically residual soil on ridges.

The effect of weathering on quartzites is seen in widening of joints, their slight discoloration, or infilling by silt. But the rock generally remains strong. On the other hand, the shists and phyllites strongly change their colour (become green, yellow, and brown), get a smoother surface, and the rock around joints and foliation loses its strength. On the other hand, the meta-daimictite, when weathered, is generally covered by a thin crust of calcite leached from the rock. The clasts of dolomite and limestone either are transformed into dissolution cavities or their colour has yellow or brown tints.

Jointing: Three discontinuity sets are seen in the Chhera Khola project area, the three sets are almost perpendicular to each other, especially in quartzites. The schists and phyllites contain rough and wavy joints that do not continue for more than 3 or 5 m. On the other hand, the meta-diamictite contains very irregular joints. The joints are straight to slightly wavy in the quartzites, where their aperture ranges from less than 1 mm to 5 mm, but some joints are rather wide (up to 1 cm) and continue for several tens of metres.

Stability conditions: The rock soil slopes in the project area are gnerally stable. Some past instabilities (but presently difficult to delineate) were noticed around Badaban, where thick (more than 10 m) colluvial deposits are present. The main source of sediments is the debris flow in the Chhera Khola from its tributaries, such as the Salma Khola, the Saru Gad, and the Suwa Gad. Landslides are seen to occur on colluvial slopes and steep rock slopes (controlled by joints). Mainly debris slides, wedge slides, and plane rockslides are found. The failure of the upper cliff generated talus deposits at the lower reach.

The highest flood level in the Chhera Khola is about 3 to 5 m from the general flow level. Owing to the frequent debris flows from the tributary streams, the water in the Chhera Khola becomes excessively turbid most of the time in the monsoon season. Hence, some measures are required to deal with this problem. On the other hand, it is clean and clear during the dry period.

Groundwater conditions: The Chhera Khola, Salma Khola, and other smaller tributaries are perennial whereas minor gullies are seasonal. There is a spring at Managad village and it issues from the talus deposits of quartzite. The quartzites and schists are quite impervious and the dam constructed on them or the tunnel passing through them should not pose any serious water ingress problems.

1.2 Dam axis

The proposed dam axis (Figures 1.6) lies in the meta-diamictite exposed on both banks of the Chhera Khola. The previously identified dam axis was found not appropriate owing to the occurrence of thick colluvial deposits on the right bank. A minor seepage and a saturated colluvial soil was also observed at the upper part of the the previous dam axis. Therefore the dam axis was shifted further south, towards the downstream by about 100 m. The newly proposed dam axis (Figures 1.7 and 1.8) has rock exposures on both banks where the Chhera Khola makes a narrow gorge. The dam axis consists of the meta-daimictite with poorly developed joints where the rock is categorised as good or fair.

The area around the new dam axis is stable and the Chhera Khola has a straight course to the downstream of that area where the slopes are dry. The dam foundation and the area around the dam axis are impervious and does not pose any serious threat of seepage.

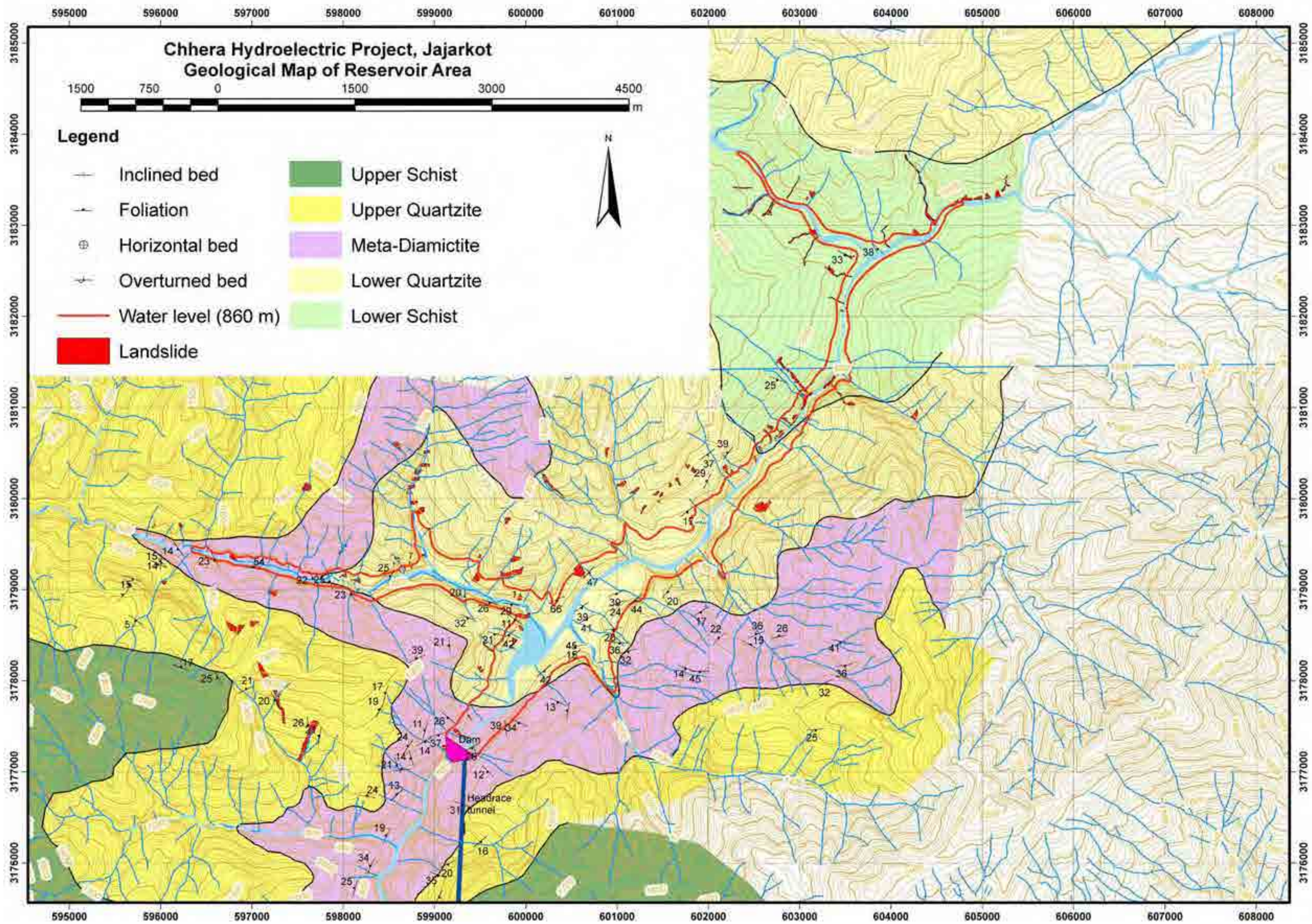

Figure 1.6: Geological map of the dam site, intake, and the reservoir area

Figure 1.7: Proposed dam axis at WPT 27. View to SE.

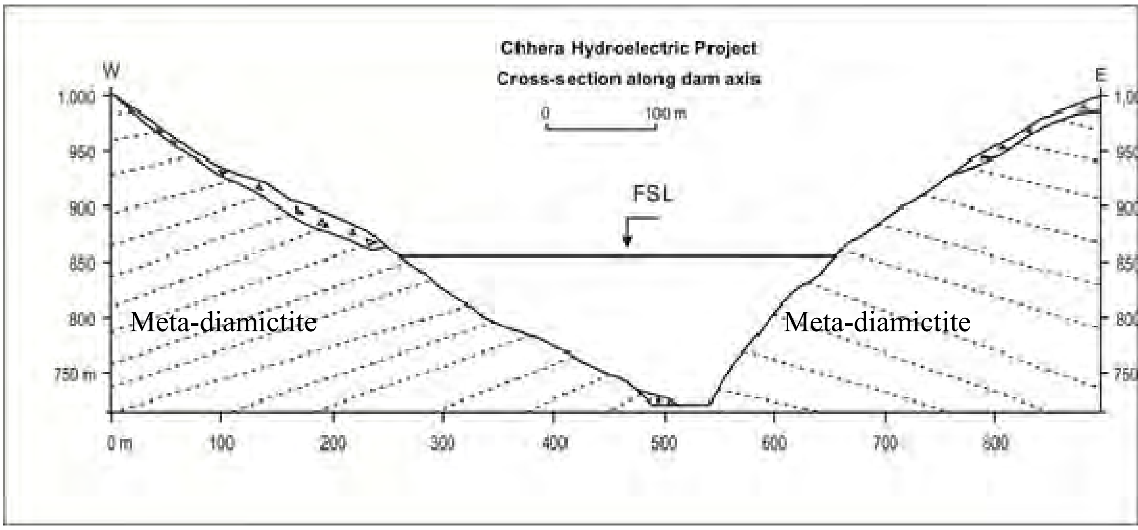

Figure 1.8: Cross-section along proposed dam axis at WPT 27.

However, the foliation around the dam axis is variable. It is almost horizontal to dipping due NW or SW (Figure 1.9). Since the calcareous clasts in the meta-diamictite are generally less than a few centimetre in size and their proportion is less than 5 or 10%, their role could be insignificant. However, the calcareous nature of the meta-diamictite should be studied in more detail.

The distribution of joints around the dam axis is presented in Figure 1.9, where the gently dipping prominent foliation and rather random but steeply dipping joints are evident.

It is proposed to construct a rock-fill dam, since there is a narrow gorge, the quartzites exposed around Managad and the Salma Khola can be utilised to obtain boulders, and the red clay is available in the vicinity of the Chhera Chaur, located about 10 km downstream on the right bank of the Bheri River.

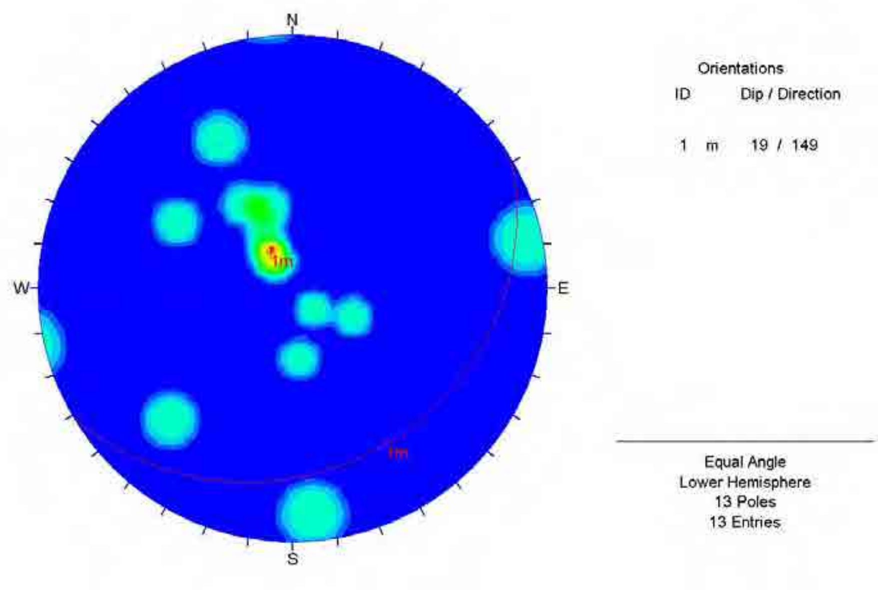

Figure 1.9: Stereographic projection of discontinuities at the dam axis around WPT 27. The major concentration represents foliation.

1.3 Reservoir

The water level (660 m) in the proposed reservoir extends up to Thalah and Badaban, in the two main tributaries of the Chherra Khola, i.e. the Saru Gad and the Suwa Gad, in the Salma Khola, and in the Ritha Khola., Similarly, the villages Jyula, Changkhil, Managar, Silpa, Panichaur, and Sirpachaur will also be under water. The engineering geological map of the reservoir and its surrounding areas is presented in Figure 1.10 and their distribution is summarised in Table 1.1.

The stability in the surrounding areas of the reservoir is relatively sound. There are no significant weak or vulnerable zones leading to dam collapse or large failures obstructing the reservoir.

Table 1.1: Distribution of rock, soil, and instabilities near the dam site, in the reservoir area, and its vicinity (based on field observations and satellite image interpretation).

Material type	Area, sq m	Per cent
Alluvium	856,374	2.1
Colluvium	21,464,857	51.7
Residual soil	100,532	0.2
Rock	19,126,689	46.0
Total	**41,548,452**	**100.0**
Instabilities	367730	0.89

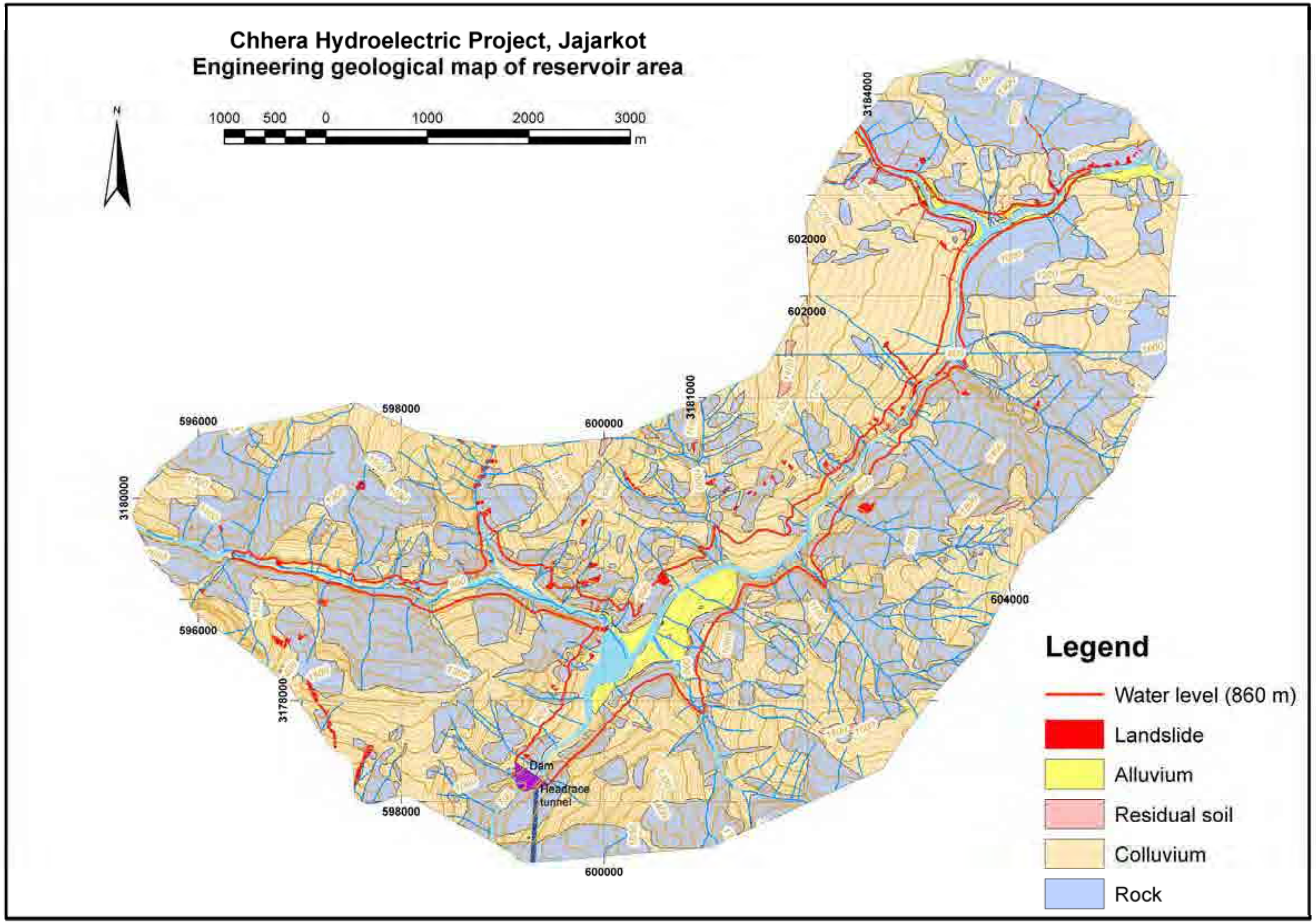

Figure 1.10: Engineering geological map of the reservoir and its surrounding region

The area to be under water consists of bedrock with some talus cones and minor instabilities. The deep, straight gorge is quite suitable for the dam construction. However, there will be significant sediment transport from the Salma Khola, which has many landslides and debris flow deposits upstream from the reservoir area. Hence some check dams and other sediment retention structures are required to prevent the sediment inflow in the reservoir.

1.4 Water way

An intake tunnel (Figure 1.11) is proposed on the left bank of the Chhera Khola, near the east end of the dam. The area is made up of meta-diamictite and it has a steep rock cliff. The cross-section along the waterway is given in Figure 1.12.

The proposed tunnel passes basically through the meta-diamictite for about 950 m, in the quartzites for about 760 m, and through alternating schists and quartzites for about 2600 m (Figure 1.11). Generally the headrace tunnel alignment makes an acute angle with the foliation. In this area, the foliation is moderately to gently dipping due south of southeast.

The overburden along the proposed headrace tunnel varies from less than 50 m to about 500 m. Owing to the gentle dip of foliation some precautions are required during construction to overcome roof collapse.

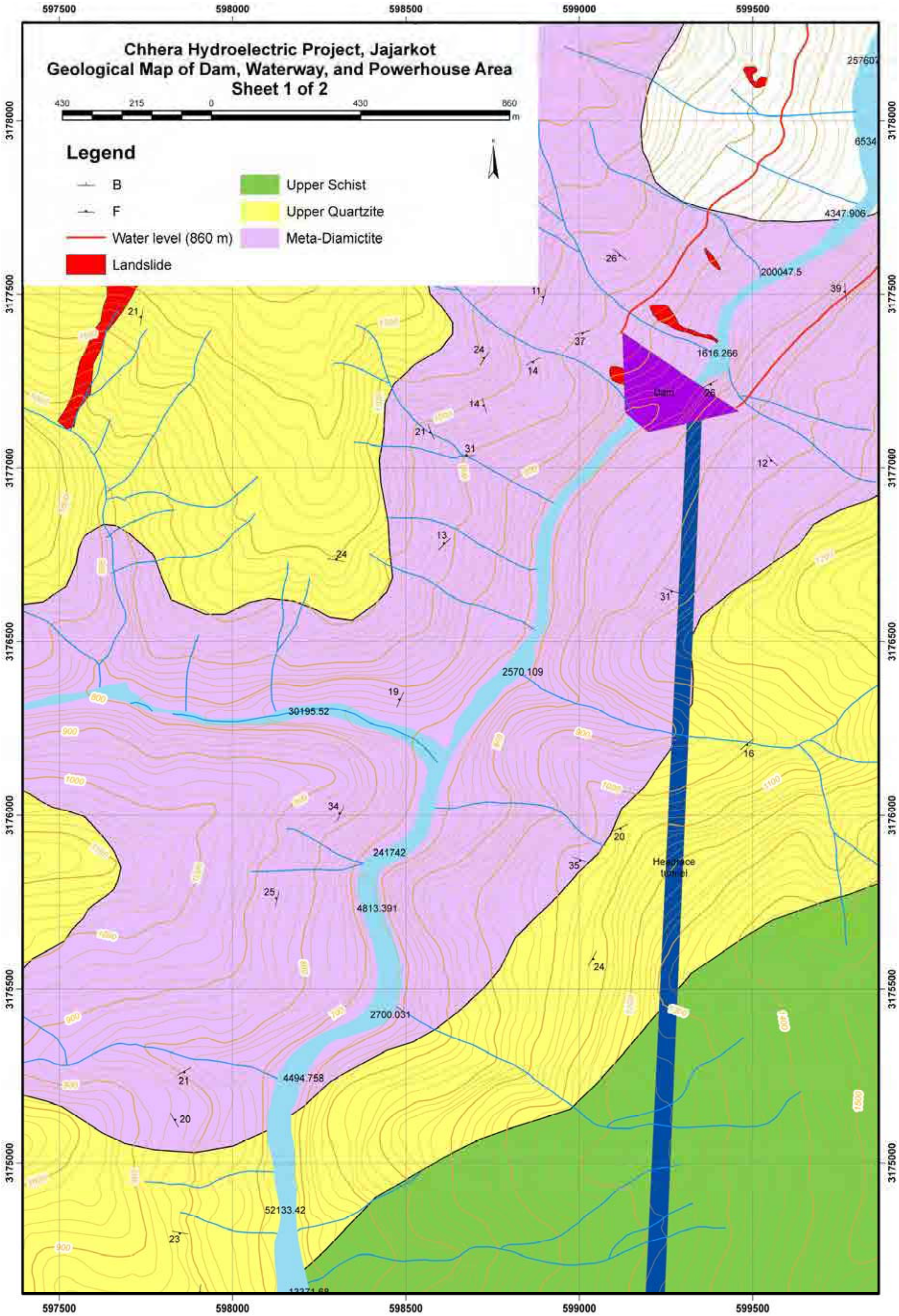

Figure 1.11: Geological map of the dam site, waterway, and powerhouse area, the Chhera Khola hydroelectric project

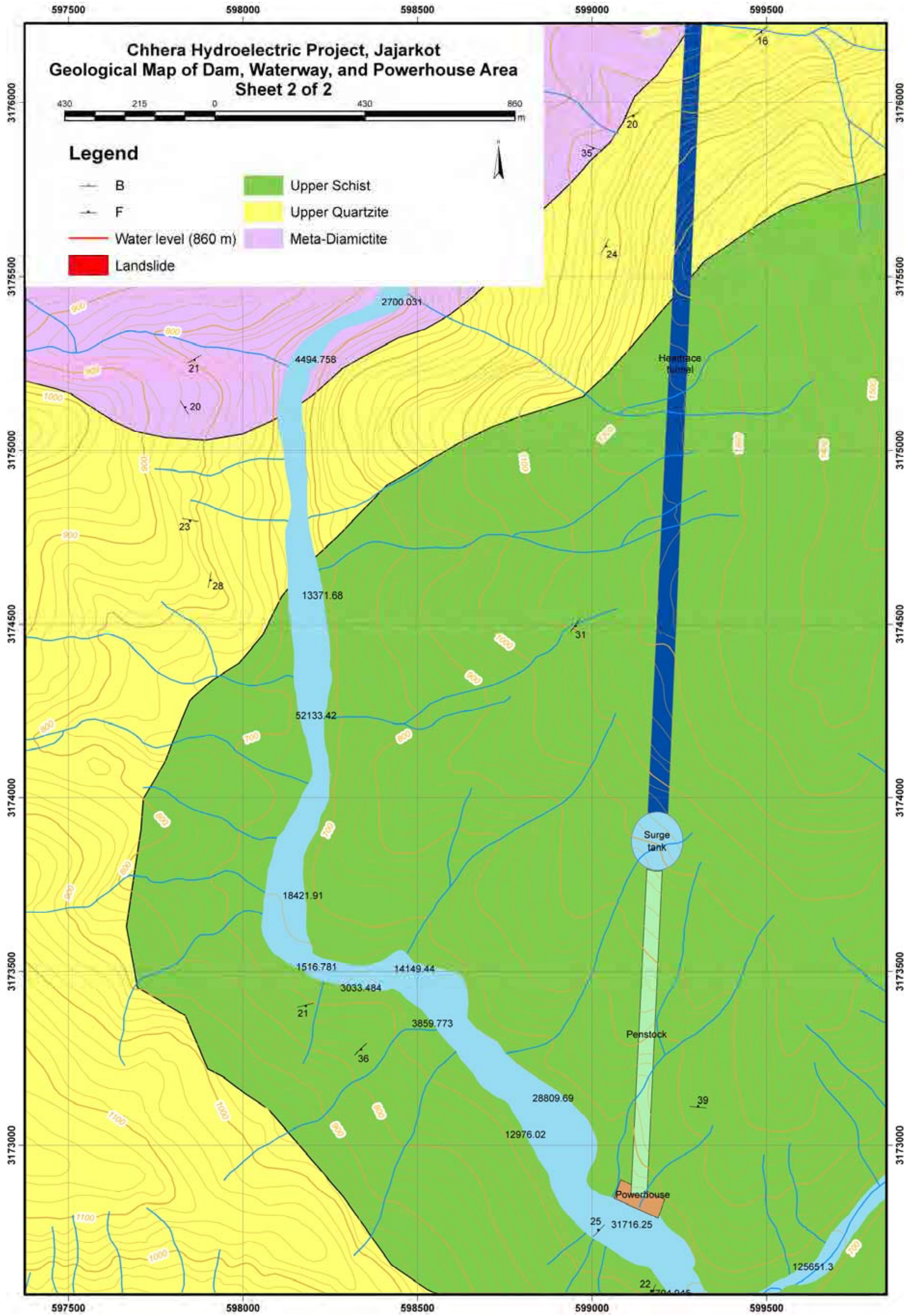

Figure 1.11（continued）： **Geological map of the dam site, waterway, and powerhouse area, the Chhera Khola hydroelectric project**

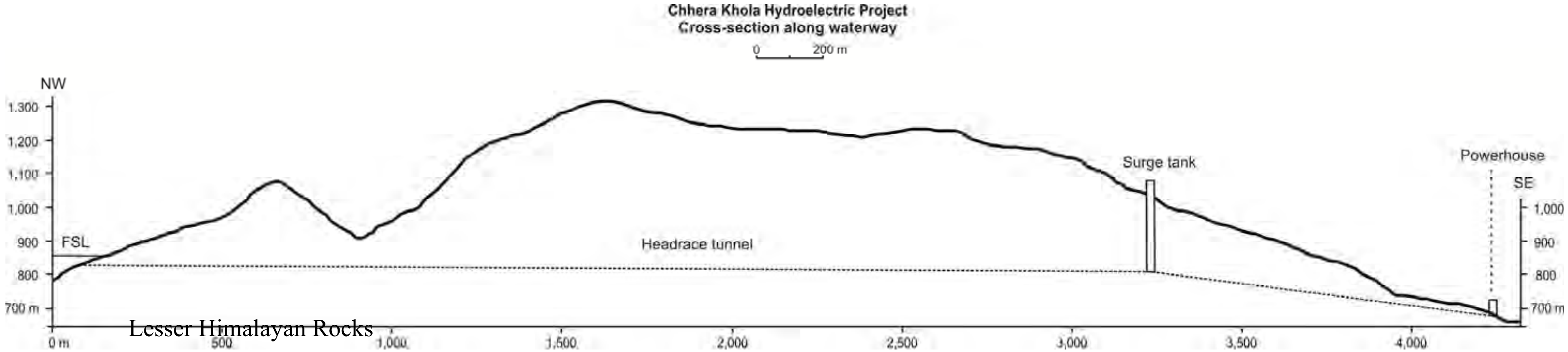

Figure 1.12: Cross-section along the waterway of the Chhera Hydroelectric Project

Lesser Himalayan Rocks

1.5 Powernouse

The powerhouse site (Figures 1.11, 1.12, 1.13) is located about 8 km downstream, below Karkigaun, to the north of the Marka Bazaar, on the left bank of the Chhera Khola (Figure 1.14) at Karkigaun on an alluvial fan which is about 50 m wide and 100 m long. There about 50 m high quartzite cliff at the powerhouse site.

Below the powerhouse site, there is about 200 m long (from the east to west) and about 75 m wide lower alluvial fan. To the east of the fan lies about 200 m long and from 75 to 100 m wide sand and gravel bar of the Chhera Khola.

At the powerhouse site, the rock is thick-banded quartzite with sporadic schist partings. The distribution of discontinuities at the powerhouse site is depicted in Figure 1.15, where three almost mutually perpendicular sets are evident. The gently NW dipping set represents the mean trend of foliation.

There is some possibility of channel shifting (by scouring the alluvial terrace, about 200 m upstream from the powerhouse site) by the Chhera Khola and damming of the Chhera Khola by the debris flow from the Sot Khola (Based on local inquiry and the inspection of the fan). Such damming took place about 42 years ago.

1.6 Instabilities

Mainly rockslides (wedge and plane failures) are observed on quartzites, meta-diamictite, and schists. The landslide and other istability distribution (Figure 1.10) in the reservoir and its vicinity was assessed from field observations and satellite image interpretations. Some important landslides are shown in Figures 1.16 and 1.17 whereas a large alluvial fan to be submerged in the reservoir area is depicted in Figure 1.18. The instabilities contribute about 367000 sq km (Table 1.1) or about 0.89 per cent of the total mapped area (Figure 1.10).

1.7 Construction materials

The required amount of gravel, sand, and fines is available at the dam site and near the confluence of the Chhera Khola and Salma Khola. Also the quartzites and their talus around Jyula and Managar could be good sources of boulders and gravel. However, sand is not available, and it is needed to transport from the Bheri River, about 10 km downstream from the dam site.

1.8 Further recommendations

The Chhera Khola hydroelectric project is geologically sound and feasible. However some further investigations are required to asses the dam site for dissolution of calcareous meta-diamictite, investigation of the headrace tunnel alignment for its stability, and study of channel shifting in the powerhouse area.

Figure 1.13: Proposed powerhouse site on the right bank of the Chhera Khola (WPT 135). View to NE.

Figure 1.14: A close-up view of the powerhouse site (near WPT 135). View to NE.

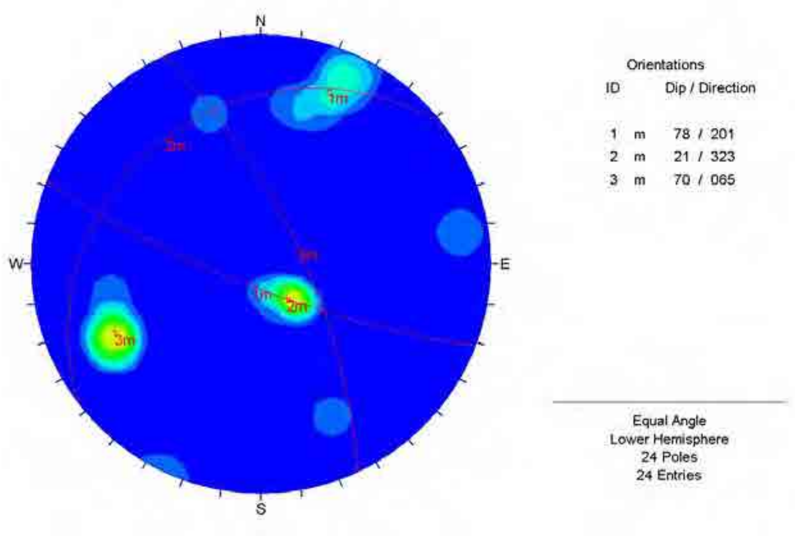

Figure 1.15: Orientation of discontinuities at the powerhouse site (around WPT 138). The first and third sets represent joints whereas the second set is foliation.

Figure 1.16: Landslide on the both banks of the Chhera Khola at the Badaban village (WPT 30). View to E

Figure 1.17: Rock falls and slides at the Badaban village (near WPT 30). View to NW.

Figure 1.18: Alluvial fan of the Salma Khola at Jyula as seen from the dam axis, left bank of the Cherra Khola (near WPT 36). View to N.

1.9 GPS survey and photos

Since each group had three geologists and only one GPS, the two geologists put the observation points directly on the map without the help of GPS, based on ground truth. The GPS data and photos are already submitted and the main photos are described below.

Table 1.2: GPS and dip-strike measurements in the Chhera Khola area

WPT	Altitude, m	Creation date time	Strike	Dip direction	Dip azimuth	Angle of dip	Bedding or Foliation
4	606	2012-07-10T02:01:09Z					
5	704	2012-07-10T02:39:15Z	105	N	15	32	F
6	725	2012-07-10T03:05:16Z	83	NW	353	35	F
7	656	2012-07-10T03:36:27Z	74	NW	344	29	F
8	644	2012-07-10T03:50:39Z	85	NW	355	30	F
9	620	2012-07-10T04:10:03Z	110	NE	20	44	F
10	621	2012-07-10T04:23:36Z	94	N	4	40	F
11	643	2012-07-10T06:09:29Z	25	NW	295	20	F
12	649	2012-07-10T06:33:31Z	41	NW	311	46	F
13	631	2012-07-10T07:23:57Z	36	NW	306	34	F
14	651	2012-07-10T08:28:08Z	60	NW	330	41	F
15	672	2012-07-10T09:17:05Z	46	SE	136	36	F
16	684	2012-07-10T09:31:22Z	76	SE	166	21	F
17	699	2012-07-10T10:59:55Z	100	SW	190	23	F
18	719	2012-07-10T11:38:23Z	60	SE	150	21	F
19	693	2012-07-11T01:15:52Z	10	E	100	28	F
20	719	2012-07-11T01:34:40Z	150	NE	60	20	F
21	726	2012-07-11T02:05:31Z	15	NW	285	25	F
22	726	2012-07-11T02:18:46Z	25	NW	295	34	F
23	679	2012-07-11T02:57:25Z	25	NW	295	19	F
24	767	2012-07-11T03:24:08Z	46	N	316	13	F
25	789	2012-07-11T04:01:26Z	85	N	355	31	F
26	818	2012-07-11T04:02:11Z	60	SE	150	14	F
27	817	2012-07-11T04:14:42Z	75	SE	165	37	F
28	792	2012-07-11T08:17:35Z	53	SE	143	17	F
29	832	2012-07-11T08:41:09Z	25	NW	295	29	F
30	899	2012-07-11T09:16:42Z	38	NW	308	39	F
31	818	2012-07-	120	SW	210	33	F

WPT	Altitude, m	Creation date time	Strike	Dip direction	Dip azimuth	Angle of dip	Bedding or Foliation
		11T10:26:16Z					
32	828	2012-07-11T11:11:07Z	135	SW	225	38	F
34	927	2012-07-11T12:26:29Z	110	S	200	25	F
35	982	2012-07-11T12:56:37Z	54	SE	144	37	F
36	619	2012-07-12T01:49:55Z	59	SE	149	42	F
37	685	2012-07-12T02:13:31Z	64	SE	154	66	F
38	705	2012-07-12T02:50:01Z	41	SE	131	47	F
39	769	2012-07-12T03:13:40Z	69	SE	159	39	F
40	798	2012-07-12T04:06:08Z	60	SE	150	41	F
41	768	2012-07-12T04:27:11Z	46	NW	316	45	F
42	779	2012-07-12T04:48:57Z	80	S	170	15	F
44	1052	2012-07-12T06:07:52Z	10	NW	280	17	F
45	1019	2012-07-12T06:21:08Z	115	SW	205	13	F
46	986	2012-07-12T06:42:37Z	115	SW	205	34	F
47	992	2012-07-12T06:53:44Z	174	W	264	39	F
49	896	2012-07-12T07:29:10Z	62	SE	152	26	F
50	907	2012-07-12T08:14:27Z	51	SE	141	42	F
51	755	2012-07-12T08:52:17Z	54	SE	144	39	F
52	723	2012-07-12T11:00:01Z	125	SW	215	11	F
53	727	2012-07-12T11:27:48Z	97	SW	187	29	F
54	732	2012-07-12T11:30:58Z	107	SW	197	26	F
55	737	2012-07-12T11:43:58Z	175	W	265	20	F
56	766	2012-07-12T12:19:18Z	26	NW	296	25	F
57	779	2012-07-12T12:44:35Z	152	SW	242	23	F
58	853	2012-07-13T02:40:48Z	130	SW	220	26	F
59	884	2012-07-13T03:00:09Z	15	NW	285	11	F
60	900	2012-07-13T03:10:32Z	35	NW	305	24	F
61	927	2012-07-13T03:19:35Z	164	W	254	14	F
62	916	2012-07-	158	SW	248	21	F

WPT	Altitude, m	Creation date time	Strike	Dip direction	Dip azimuth	Angle of dip	Bedding or Foliation
		13T03:31:05Z					
63	986	2012-07-13T03:51:43Z	100	N	10	24	F
66	1214	2012-07-13T05:50:44Z	10	NW	280	21	F
67	1249	2012-07-13T06:02:40Z	168	SW	258	26	F
68	1305	2012-07-13T06:19:26Z	150	SW	240	20	F
69	1349	2012-07-13T06:32:42Z	65	NW	335	21	F
70	1422	2012-07-13T06:54:39Z	150	SW	240	25	F
71	1431	2012-07-15T02:16:09Z	113	N	23	17	F
72	1369	2012-07-13T09:12:12Z	125	S	215	5	F
73	1326	2012-07-13T09:39:00Z	45	NW	315	5	F
74	1250	2012-07-13T09:50:12Z	135	SW	225	11	F
75	1180	2012-07-13T10:00:43Z	110	S	200	15	F
76	1031	2012-07-13T10:21:21Z	115	SW	205	12	F
77	999	2012-07-13T10:30:01Z	135	SW	225	14	F
78	947	2012-07-13T10:39:48Z	5	W	275	15	F
79	879	2012-07-13T10:56:25Z	145	SW	235	14	F
80	867	2012-07-13T11:23:29Z	150	SW	240	23	F
81	849	2012-07-13T11:42:43Z	100	N	10	54	F
82	828	2012-07-13T11:59:13Z	146	SW	236	22	F
83	817	2012-07-13T12:19:18Z	164	W	254	25	F
84	922	2012-07-14T03:27:12Z	80	SE	170	20	F
85	996	2012-07-14T03:51:24Z	92	S	182	36	F
86	1083	2012-07-14T04:42:50Z	75	SE	165	32	F
88	1355	2012-07-14T05:58:44Z	110	SW	200	14	F
89	1430	2012-07-14T07:08:41Z	90	S	180	45	F
90	1560	2012-07-14T08:30:03Z	172	E	82	43	F
91	1634	2012-07-14T08:58:21Z	85	S	175	25	F
92	1592	2012-07-14T09:22:56Z	62	SE	152	32	F
93	1548	2012-07-	80	SE	170	36	F

WPT	Altitude, m	Creation date time	Strike	Dip direction	Dip azimuth	Angle of dip	Bedding or Foliation
		14T10:18:10Z					
94	1574	2012-07-14T10:34:51Z	100	S	190	41	F
95	1428	2012-07-14T11:28:54Z	79	NW	349	26	F
96	1291	2012-07-14T11:53:13Z	66	NW	336	36	F
97	1203	2012-07-14T12:10:41Z	120	NE	30	15	F
98	1172	2012-07-14T12:26:49Z	45	NW	315	22	F
99	1179	2012-07-14T12:43:36Z	57	SE	147	17	F
100	1132	2012-07-14T13:03:47Z	36	SE	126	20	F
101	969	2012-07-14T13:29:34Z	52	SE	142	44	F
102	903	2012-07-15T02:11:47Z	70	SE	160	24	F
103	808	2012-07-15T02:09:11Z	105	SW	195	21	F
104	940	2012-07-15T02:57:51Z	115	SW	205	32	F
105	1149	2012-07-15T04:08:06Z	175	W	265	21	F
106	1214	2012-07-15T04:09:16Z	65	NW	335	39	F
107	1229	2012-07-15T04:31:44Z	15	W	285	17	F
108	1246	2012-07-15T04:43:44Z	28	W	298	19	F
109	1021	2012-07-15T10:16:59Z	135	SW	225	12	F
110	1089	2012-07-15T10:46:57Z	110	SW	200	31	F
111	1049	2012-07-15T11:08:59Z	50	SE	140	16	F
112	1105	2012-07-15T11:31:45Z	65	SE	155	20	F
113	1139	2012-07-15T11:44:07Z	110	S	200	35	F
114	1262	2012-07-15T12:12:48Z	28	SE	118	24	F
115	1202	2012-07-16T05:13:45Z	35	SE	125	31	F
116	931	2012-07-16T05:11:01Z	95	NE	5	39	F
117	697	2012-07-16T05:17:15Z	71	NW	341	40	F
118	695	2012-07-16T05:27:58Z	150	NE	60	18	F
119	692	2012-07-16T05:53:53Z	122	NE	32	33	F
120	698	2012-07-16T06:12:49Z	176	E	86	21	F
121	758	2012-07-	97	S	187	18	F

WPT	Altitude, m	Creation date time	Strike	Dip direction	Dip azimuth	Angle of dip	Bedding or Foliation
		16T06:33:55Z					
122	774	2012-07-16T07:05:16Z	70	NW	340	11	F
123	746	2012-07-16T07:02:44Z	103	NE	13	24	F
124	684	2012-07-16T07:28:23Z	129	NE	39	24	F
125	725	2012-07-16T08:28:47Z	90	N	360	39	F
126	729	2012-07-16T08:46:01Z	131	NE	41	27	F
127	747	2012-07-16T09:24:11Z	122	NE	32	35	F
128	785	2012-07-16T10:11:12Z	98	NE	8	16	F
129	779	2012-07-16T10:33:11Z	120	NE	30	11	F
130	805	2012-07-16T11:11:22Z	48	SE	138	25	F
131	764	2012-07-16T12:25:58Z	105	NE	15	19	F
132	591	2012-07-17T01:33:23Z	80	N	350	30	F
133	638	2012-07-17T01:54:57Z	92	N	2	29	F
134	642	2012-07-17T02:11:45Z	25	NW	295	22	F
138	640	2012-07-17T03:14:58Z	45	NW	315	25	F

Table 1.3: List of Photographs taken in the Chhera Khola area, Jajarkot

Photo number	***Description***
DSC00121	Confluence area of the Chhera Khola and the Bheri River; view to SE
DSC00129	Powerhouse site located on the left bank of the Chhera Khola opposite a house; view to N
DSC00142	Proposed dam axis; view to SE
DSC00144	Proposed dam axis showing both banks; view to SE
DSC00145	people paddy plantation to be under water around proposed dam site at Jyula
DSC00151	Landslide on the left bank of the Chhera Khola at Badaban village; view to E
DSC00153	Landslide on the both banks of the Chhera Khola at Badaban village; view to E
DSC00154	Landslide on the right bank and few streams on the left bank of the Chhera Khola at Badaban village; view to NE
DSC00155	Landslide (crown area) destroying cultivated land on the right bank of the Chhera Khola; view to NE
DSC00160	Rock falls around the village with boulders of quartzite ranging in size from 50 cm to 3 m; view to NW
DSC00162	Suspended bridge over the Chhera Khola at Sarugad village; view to NW
DSC00163	Uppermost houses of the Sarugad Village to be under water and landslide on the opposite bank; view to NE

DSC00165	Landslide on schist and amphibolites on the right bank of the Chhera Khola opposite to Sarugad village; view to NE
DSC00167	Thalaha village on the left bank of the Chhera Khola to be under water; view to SW
DSC00171	Confluence of the Sarugad Khola and the Suwa Khola, the area to be in the submerged zone in the Suwa Khola; view to W
DSC00176	The Kaldunga Khola flowing on thick quartzite showing wedge slide; view to S
DSC00179	Managad village on the right bank of the Chhera Khola to be under water; view to NE
DSC00187	Managad village to be under water and tallus deposit on the opposite bank; view to NE
DSC00189	Confluence of the Salma Khola and the Chhera Khola at Jyula Bazaar; view to W
DSC00190	General view of the Chhera Khola and the Salma Khola at Jyula; the Salma Khola has created a large alluvial fan at its confluence with the Chhera Khola.
DSC00193	Earlier proposed dam axis; view to NW
DSC00194	Newly proposed dam site; view to NW
DSC00201	Wedge slide on quartzite on the left bank of the Salma Khola; view to NE
DSC00202	Quartzite cliff on the opposite bank of the Salma Khola near the confluence of the Jewa Khola and the Salma Khola; view to S
DSC00209	Rock slide about 75m wide and 30 m high on the left bank of the Salma Khola; view to NE
DSC00218	A landslide (Rockslide) about 30 wide and 30 m high on the concave left bank of the Salma Khola
DSC00221	A big talus on the right bank of Chhera Khola opposite the Managad village; view to NW
DSC00223	Inferred Higher Himalayan rocks to the north of Thalaha Bazaar; view to NE and the Higher Himalaya in the background
DSC00226	The Salma Khola; view to NW
DSC00228	A general view of the Salma Khola; view to NW, the Madhya Pahadi Rajmarg in the background
DSC00234	Colluvium (talus) in the dam area; view to NW
DSC00237	The Managad village on the left bank, Jyula on the right bank of the Chhera Khola and the confluence of the Salma Khola and the Chhera Khola; view to NE
DSC00246	A wide point bar created by the Chhera Khola at Baluwa Bazaar, a possible sand and gravel burrow site; view to SW
DSC00259	Proposed powerhouse area
DSC00272	Alluvial terrace in the proposed powerhouse area at Amarsina (Karkigaun)
DSC00274	Cut bank representing the left concave bend of the Chhera Khola; viewing upstream
DSC00275	A ledge at the concave cut bank of the Chhera Khola near the proposed powerhouse area; viewing S
DSC00280	The Sot Khola fan that had dammed the Chhera Khola in Chaitra 15, 2027 B.S.
DSC00281	House of Kamba Sing at the proposed powerhouse area, also about (200 m × 50 m × 7 m) sand deposit.
DSC00286	Quartzite cliff near the proposed powerhouse area

Table 1.4: GPS locations of photographs taken in the field

WPT	Altitude, m	Creation date time	Photo No.
5	704	2012-07-10T02:39:15Z	1 to 5
6	725	2012-07-10T03:05:16Z	6 to 10
11	643	2012-07-10T06:09:29Z	11, 12
13	631	2012-07-10T07:23:57Z	13 to 16
14	651	2012-07-10T08:28:08Z	17,18
17	699	2012-07-10T10:59:55Z	19 to 23
22	726	2012-07-11T02:18:46Z	26 to 30
27	817	2012-07-11T04:14:42Z	31 to 35
28	792	2012-07-11T08:17:35Z	36, 37
29	832	2012-07-11T08:41:09Z	38, 39
30	899	2012-07-11T09:16:42Z	40 to 49
32	828	2012-07-11T11:11:07Z	50 to 61
33	879	2012-07-11T12:02:58Z	62 to 65
35	982	2012-07-11T12:56:37Z	66, 67
38	705	2012-07-12T02:50:01Z	68 to 70
39	769	2012-07-12T03:13:40Z	75 to 77
49	896	2012-07-12T07:29:10Z	82, 83
52	723	2012-07-12T11:00:01Z	84, 85
55	737	2012-07-12T11:43:58Z	86 to 90
57	779	2012-07-12T12:44:35Z	91
80	867	2012-07-13T11:23:29Z	95 to 97
82	828	2012-07-13T11:59:13Z	106 to 110
89	1430	2012-07-14T07:08:41Z	115, 116
100	1132	2012-07-14T13:03:47Z	134, 135
110	1089	2012-07-15T10:46:57Z	138 to 140
137	652	2012-07-17T02:56:30Z	147 to 168

Table 1.5: Geological Study Team Members and Itinerary of the Field Visits

Name of Project	District	Date of field visit	Name of the Geologlist	Investigation method
Chera-1	Jajarkot	8th July – 19th July, 2012	Dr. Megh Raj Dital Mr. Narayan Adhikari Mr. Santosh Adhikari	Geological reconnaissance survey

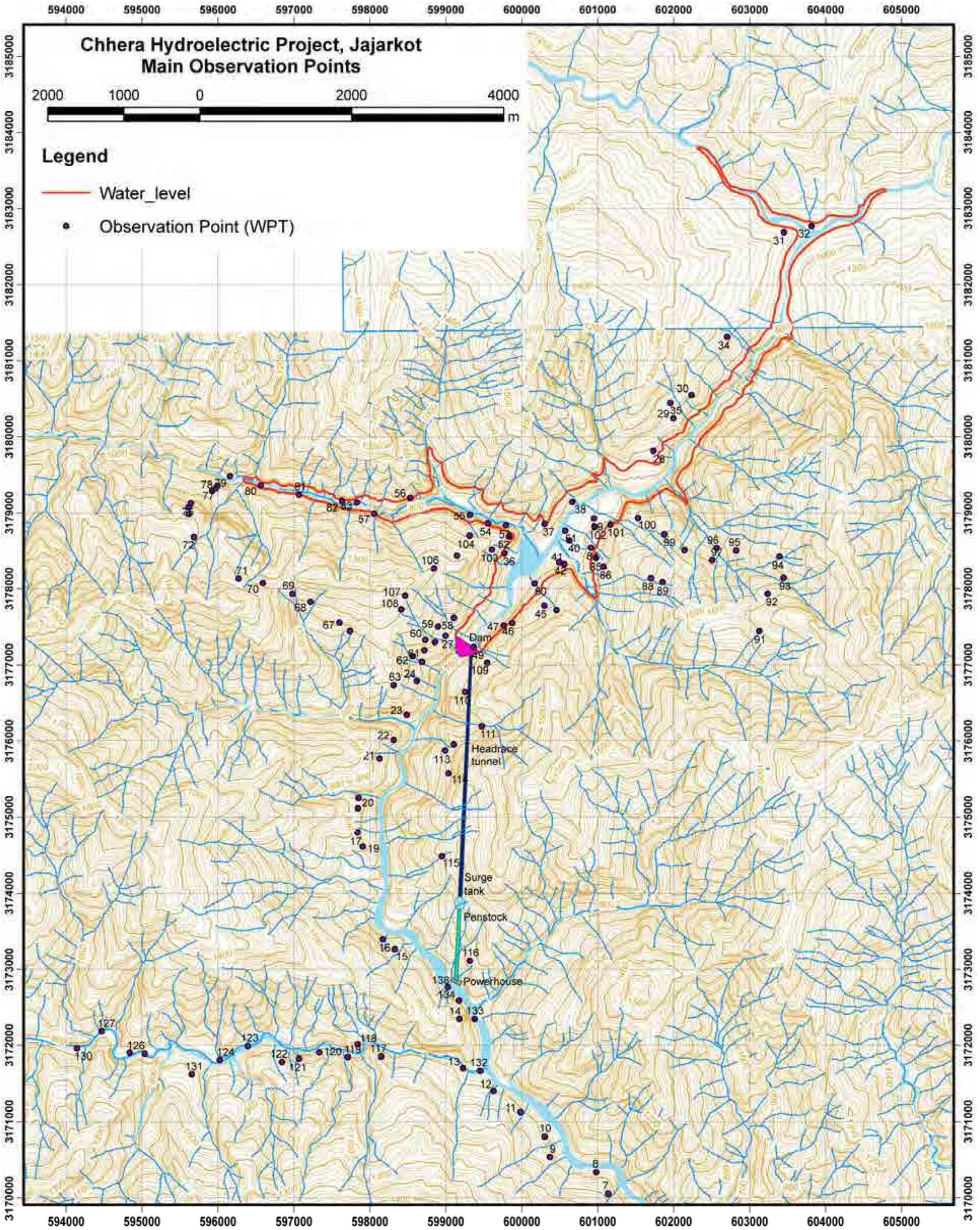

Figure 1.19: Location of of main observation points